



AIRCRAFT SURVIVABILITY

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LIVE FIRE TEST and Evaluation



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



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On the cover: An F-35C Lightning II launches from a U.S. Navy carrier in this artist's rendering. The aircraft's Very Low Observable stealth is designed to require little maintenance, even in the harsh carrier-deck environment.

Lockheed Martin Corporation.

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by Renee Hatcher

The Naval Air Warfare Center Weapons Division Weapons (NAWCWD) Survivability Lab at China Lake recently developed and verified the capability to accurately and realistically test, evaluate, and document the effects of a Man Portable Air Defense System (MANPADS) impact on aircraft in an effort to make them more survivable. This capability is unique to China Lake, and is known as the Missile Engagement Threat Simulator (METS).

16 Arcing Survivability

by Colin McCabe and Patrick O'Connell

Fire represents a significant vulnerability to all air vehicle systems. Combat aircraft in particular are at risk due to the potential to encounter enemy threats that can ignite flammable fluids, including the onboard fuel, which can represent a significant portion of the aircraft's internal volume. These threats can either directly ignite a fire due to their own energy, or indirectly contribute to fire ignition when the threat penetrates another potential ignition source.

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19 Excellence in Survivability—Robert E. Walther

by Eric Edwards

The Joint Aircraft Survivability Program Office is pleased to recognize Mr. Robert E. Walther for Excellence in Survivability. With more than 50 years of Department of Defense (DoD) experience—including work as a Navy officer, Army civilian, and contractor—Bob has played a significant role in testing and analyzing the survivability/lethality of numerous combat systems.

21 2009 NDIA CSD Aircraft Survivability Awards and Presentations

by Dennis Lindell

The National Defense Industrial Association's (NDIA) Combat Survivability Division (CSD) held its annual Aircraft Survivability Symposium at the Naval Postgraduate School (NPS) on 3–6 November 2009. The Aircraft Survivability 2009 theme was “Next Generation Requirements.” As the theme implies, the symposium explored new approaches to integrate and balance aircraft survivability for today’s war on terrorism, while remaining prepared for future high-intensity conflicts.

23 Simple Automatic Fire Suppression

by Joe Manchor

In-flight fire can be disastrous, especially if occurring in a large open space, such as the main cabin area of a rotorcraft. To combat fire, most aircraft are equipped with hand-held extinguishers. But fires may occur in inaccessible areas that may not be reached with the hand-held extinguisher. Additionally, flammable fluid fires, such as those that may occur after enemy encounters, can be particularly difficult to extinguish. For such fires, it is often important to extinguish as quickly as possible to prevent the spread of burning fuel to the point that the fire becomes unmanageable.

24 Joint Cargo Aircraft Hydrodynamic Ram LFT&E

by Scott Wacker, Marcus Miller, and Dan Cyphers

The Joint Cargo Aircraft (JCA) Program is a joint US Army/US Air Force program formed to procure, field, and sustain a multifunctional fixed wing cargo aircraft. The JCA’s primary mission is to provide direct support airlift of time-sensitive, mission-critical cargo to Army forces operating in remote, austere areas. The current concept of employment envisions the JCA flown by Air National Guard units under the tactical control of Army Combat Aviation Brigades or Aviation Task Forces.

29 Joint Cargo Aircraft LFT&E Program

by Steven Duda

The Joint Cargo Aircraft or JCA (C-27J) is an intra-theater fixed wing cargo aircraft intended to deliver time-sensitive cargo to the last tactical mile. The program started as an Army program to replace and consolidate the Army’s fixed wing cargo fleet of C-23 and certain C-12 aircraft. The program was later directed to merge with the Air Force (AF) Light Cargo Aircraft (LCA), which would augment C-130 intra-theater capabilities. The LCA would improve airlift efficiencies by eliminating the need to fly mostly empty C-130 aircraft to deliver small, time-sensitive loads.

by Dennis Lindell

Tracy Sheppard Receives Stein Award

On June 17, 2009, the Test and Evaluation (T&E) Division of the National Defense Industrial Association (NDIA) presented Mr. Tracy Sheppard with the 2009 Arthur Stein Award for his outstanding contributions in live fire test and evaluation (LFT&E). The award was given at the organization's LFT&E Conference at The Johns Hopkins University Applied Physics Laboratory in Laurel, MD.

"I am honored and humbled to receive this award," Mr. Sheppard said. "The men who received it before me exemplify the caliber of professionalism, dedication, and fortitude that Mr. Stein himself established during his career. I am privileged to stand among them."

Mr. Sheppard, who also delivered the conference's keynote address earlier in the day, serves as a staff specialist in the Office of the Director, Operational Test and Evaluation (DOT&E), Office of the Secretary of Defense. He has more than 20 years of experience in the research, development, test, and evaluation (RDT&E) of military systems, particularly the LFT&E of major defense acquisition programs.



Tracy Sheppard

His current responsibilities include providing guidance to the deputy director on the T&E of systems under oversight; participating on Integrated Product Teams (IPT); reporting on significant RDT&E events; reviewing and commenting on technical and engineering plans submitted for approval; maintaining a database of LFT&E lessons learned; co-managing the Joint Live Fire, Joint Technical Coordinating Group for Munitions Effectiveness, and Joint Aircraft Survivability programs; and interfacing with scientific and engineering staff throughout the Defense Department on RDT&E-related matters. Mr. Sheppard also serves on the Joint Improvised Explosive Device (IED) Defeat Joint Test Board and is an action officer for numerous non-Title programs.

Mr. Sheppard began his government career as an infantryman in the US Marine Corps in the early 1980s. Following his active service, he worked as a project engineer at the US Army Aberdeen Test Center, planning and conducting test programs on numerous combat systems. He then served the first of two stints as staff specialist at DOT&E (previously described). In addition, he was the technical director for the University of Texas at Austin's Center for Studies in Acquisition/ Washington, DC, Office, as well as an operations research analyst at the US Army Evaluation Center.

Mr. Sheppard's academic credentials include associate and bachelor degrees in electrical engineering from The Johns Hopkins University. He also serves on the board of directors for the Francis Scott Key Chapter of the International Test and Evaluation Association and lectures at the Defense Acquisition University. And he has received numerous other awards, including the NDIA Tester of the Year, the Secretary of Defense Medal for Exceptional Civilian Service, the Silver Award (Technical-Professional) from the Baltimore Federal Executive Board, and two Army Achievement Medals.

This year's Stein Award was presented by Jim O'Bryon, the chairman of the NDIA T&E Division. Before he did so, Dr. Lowell Tonnessen from the Institute for Defense Analyses provided attendees with some highlights of the career, accomplishments, and writings of the award's namesake.

"At first glance," Dr. Tonnessen said, "it might seem odd to name the Live Fire Test and Evaluation award after a man who already was semi-retired when LFT&E was Congressionally mandated, and who passed away almost 14 years ago. But Arthur Stein was not a usual person. He led a distinguished career, he made major contributions to Live Fire Test and Evaluation, and he was loved. It is for all of these reasons that we continue to give the LFT&E award in his name."

Previous recipients of the Stein Award include Dr. Tonnessen and Dr. Paul Deitz (1997), Mr. Walt Hollis (1999), Dr. Bob Ball (2000), Mr. Jim O'Bryon (2002), Dr. Ron Reese (2003), and Mr. Larry Eusonio (2007).

New ESAMS Version

SURVIAC has begun distributing the newest version of the Enhanced Surface-to-Air Missile Simulation (ESAMS) 4.1. This program and its upgrades were funded by the Joint Aircraft Survivability Program Office (JASPO) and were developed by ASC/ENDA.

The new version of ESAMS 4.1 model is an upgrade of ESAMS 4.0. ESAMS is a digital computer program used to model the interaction between a single airborne target and a surface-to-air missile (SAM) air defense system. The user may individually specify each site's location or have ESAMS arrange sites in rectangles, concentric circles, or semi-circles. The model details the characteristics of both ground and missile seeker radar. ESAMS models aircraft from their signature data and optional vulnerability data. This simulation provides a one-on-one framework used to evaluate air vehicle

survivability and tactics optimization. ESAMS can execute simple, straight and level, or complex flight paths.

Supported Platforms

- SUN
- PC—Compaq Compiler and Intel Visual FORTRAN
- Linux—Portland Compiler

ESAMS Training

If you or your company is interested in ESAMS training, please contact Paul Jeng for more information.

You can obtain the new version of ESAMS 4.1 from SURVIAC. Direct order requests to Mr. AJ Brown and technical questions to Mr. Barry Vincent.

LFT&E Conference Held at JHU-APL in June

On June 17–19, 2009, more than 150 live fire test and evaluation (LFT&E) professionals from across the country convened at The Johns Hopkins University Applied Physics Laboratory (JHU-APL) in Laurel, MD, for the National Defense Industrial Center's (NDIA) eighth LFT&E Conference. The purpose of the conference was to discuss the history, role, contributions, and challenges of LFT&E since the process was written into law more than two decades ago.

More than 50 speakers from government and industry made presentations during the three-day, classified event. Sessions included LFT&E support to/from the battlefield, the LFT&E of fixed- and rotary-wing aircraft, the LFT&E of tracked and wheeled vehicles, the LFT&E assessment of user casualties, applications of modeling and simulation (M&S) to LFT&E, and advances in LFT&E methodology. In addition, special focus was given to target representation/visualization, shotline selection assessment, rapid acquisition program LFT&E, and Department of Homeland Security LFT&E.

The keynote address for the conference was delivered by Mr. Tracy Sheppard, who serves in the Office of the Director, Operational Test and Evaluation (DOT&E), Office of the Secretary of Defense. Mr. Sheppard highlighted numerous contributions that LFT&E is making in the current conflicts in Iraq and Afghanistan and reminded attendees

of some of the statutory requirements and issues related to DOT&E's oversight of LFT&E programs.

Mr. Sheppard was also honored at the event by the NDIA T&E Executive Committee, who selected him as its latest recipient of the Arthur Stein Award (see related News Note in this issue). The award, named after long-time tester and respected analyst Art Stein, is given for outstanding contribution and lifetime achievement in LFT&E.

The conference also featured a "greybeard" panel of long-time LFT&E professionals, who offered their views on major trends, contributions, and policies affecting the LFT&E community. The panel, chaired by NDIA T&E Division Chairman Jim O'Bryon, included Dr. Paul Deitz, Dr. Lowell Tonnessen, Dr. Fred Fisch, and Mr. Dale Atkinson.

Finally, the conference provided an occasion to unveil the recently published *Fundamentals of Ground Combat System Ballistic Vulnerability/Lethality (V/L)* book. The 365-page hard-bound text—co-sponsored by the US Army Research Laboratory and DOT&E and produced by more than 50 contributors—discusses the basic language, history, and processes of V/L analysis, as well as its related tools, methodologies, and applications.

The next LFT&E conference is scheduled to be held in the Eglin Air Force Base area in June 2011.

A Hale and Hearty Farewell

CAPT Ken Branham, United States Navy (USN), finished his tour as the Joint Aircraft Survivability Program (JASP) military deputy program manager and Joint Live Fire (JLF)/Aircraft Systems joint test director in September 2009. As joint test director, CAPT Branham successfully ushered into publication more than 75 legacy JLF/Air test reports, some dating back to the 1980s. Because of his diligence and perseverance, this valuable information is now readily available to the aircraft survivability community. He did this while managing the JLF/Air program so that it exceeded performance metric goals.

CAPT Branham also strengthened the relationship between the JLF-Air program and the JASP Vulnerability Reduction and Survivability Assessment Subgroups. Of note, he led a combined team of modelers and testers in developing a JASP-JLF/Air man-portable air-defense systems (MANPADS) roadmap. Completed in the summer of 2009, the roadmap laid out aircraft MANPADS vulnerability assessment and live fire test requirements, and identified the shortfalls in our ability to analyze and test aircraft vulnerability to MANPADS. The roadmap development process generated multiple JASP and JLF/Air projects to begin addressing the identified shortfalls. The roadmap will be updated periodically to capture developments in requirements as well as analysis and test capability.

During his two years at JASP, CAPT Branham raised the bar for outreach. He led technical interchange meetings with many of the Navy PMAs, anchored the JASP presence at Navy and Marine Corps aviation conferences, and facilitated holding JASP meetings at Navy facilities in New Orleans and Key West.

The JASP thanks CAPT Branham for his support over the last two years and wishes him well.



CAPT Ken Branham, USN

JCAT Corner by CAPT Kirby Miller, USN

The Joint Combat Assessment Team ended another busy year supporting the warfighters and the Survivability Community. The one thing that we have learned over the years is that the only constant is change! This year we saw that again, whether it was the mission, the team members, or the method of support.

A Brave New World...Well, Sort of

As mentioned in the Journal's last JCAT Corner, the scope of our mission is evolving. The successes on the ground in Iraq and the challenges of Afghanistan have led to a deliberate prioritization aimed at focusing our efforts where they are needed most. We continue to support the fight in Iraq, but have been steadily shifting toward more robust support in Afghanistan.

Our full-time support in Operation Enduring Freedom, CDR Paul Kadowaki and CW5 Chris Jordan, have been busy covering a theater slightly smaller than Texas, with only a tiny fraction of the supporting infrastructure. They have done a great job in a challenging and austere environment, providing first-hand witness to the oft-said, "Afghanistan ain't Iraq!" Also supporting the fight forward, CW4 Chris Chance is in the Personnel Recovery Coordination Center in Qatar, allowing the JCAT high-level visibility in both theaters and immediate reach back to our Continental US (CONUS) components.

Speaking of CONUS, it has been busy here, too. Nothing ever just happens, and Air Force reservist Lt Col Jeff Ciesla and Navy reservist CDR Tom Mayhew have been working overtime solving Force Generation issues on a daily basis. Now that the Afghan "Surge" has been approved, we are poised to send more assessors downrange and provide more timely coverage for the entire country...as soon as the trigger is pulled!

Finally, in November, the Navy JCAT component was honored as the NAVAIR Unit of the Year for Warfighter Support. This award is also a validation of the

Joint nature of our efforts, as each service component has played a hand in the success of this vital mission.

Local Boys Made Good

A former JCAT member, Chuck Rainey, has been selected for a star! RDML Rainey was promoted October 1 in a ceremony at his alma mater, the US Naval Academy. He will serve as the director, NAVAIR Reserve Program in Patuxent River, MD. RDML Rainey has a long history with the Navy component of the JCAT, including a tour in Iraq during Phantom Fury in Fallujah and later as the commanding officer. Congratulations to RDML Rainey on a job well done!

Navy CAPT Bill Little was promoted September 12, and Lt Col Jeff Ciesla of our Air Force component was promoted October 1.

And finally, congratulations to SMSgt Rick Hoover, who was recently selected for Chief Master Sergeant. He was promoted by RDML Rainey on January 8th at Wright-Patterson AFB.



Rear Admiral Chuck Rainey takes the oath of office from Rear Admiral Steven Eastburg, Program Executive Officer for Air ASW, Assault & Special Mission Programs, at the US Naval Academy

instrumental in growing our knowledge base, bringing a wealth of experience to the table. He is moving on to serve in Germany as an RC-12 pilot.

Also departing the pattern is Navy CDR Van McKenny, officer in charge of the Navy Detachment in China Lake, CA. Van was instrumental in improving our facilities in the desert and providing the best training possible for our deploying assessors. CAPT Bill Little is moving on as well, but we may see him again soon in a slightly hotter and dustier climate... we will keep you posted. Thank you all for your service!

On the plus side, CDR Kevin Askin has reported to replace CDR McKenny in China Lake, and Col Tim Thorsen has reported as the Marine JCAT Director. Both are veterans of extended deployments to Iraq and bring a wealth of leadership experience and vision we need to take JCAT to the next level. Welcome aboard!

Threat Weapons and Effects Seminar

Don't forget...the 2010 edition of the JCAT Threat Weapons and Effects Seminar will take place 27–29 April at Hurlburt AFB, FL. Make your plans now! ■

Hails and Farewells

We always have to say goodbye to team members, and the past few months were no exception. Army CW4 Greg Calvert recently transferred after completing a successful tour with the Army component of the JCAT. Greg was

F-35 Live Fire Test: Full-Up Systems Level Testing

by Charles Frankenberger

The Joint Strike Fighter (JSF) (F-35, Lightning II) Vulnerability and Live Fire Test Team will be conducting Full-Up System Level (FUSL) testing on the 1st JSF System Design and Development (SDD) aircraft (2AA:0001). The F-35 live fire test and evaluation (LFT&E) strategy is to conduct a comprehensive test and evaluation of the system-level vulnerability and lethality of all three F-35 variants against ballistic and advanced threats. The original LFT&E strategy for determining the system-level vulnerability for the F-35 family of aircraft was founded on the FUSL testing of an F-35 short takeoff and vertical landing (STOVL) variant. The approach for the remaining two variants was to leverage the high degree of commonality between the F-35 family of aircraft by conducting Full-Up testing of the variant unique features and component/system level tests. The waiver approving this live fire (LF) strategy was approved by the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD AT&L) on 25 October 2001.



Based on a 2007 program need to perform additional STOVL flight testing, the LFT&E strategy was revised to include FUSL testing of a conventional takeoff and landing (CTOL) variant (2AA:0001), along with testing of a Full Scale Structural Test Article (FSSTA) for the carrier variant (with engine) and an FSSTA test of the STOVL variant (without engine), 2CG:0001 and 2BG:0001 respectively. Ballistic testing of the assembled STOVL propulsion system (engine, drive shaft, and lift fan) is also included in this updated approach.

The primary objective of 2AA:0001 LFT series is to evaluate the systems that support aircraft flight controls. This includes the electrical power system, the power and thermal management system, the vehicle systems network, and the flight control system itself. The testing will be conducted in a way that replicates the aircraft functions during a mission, from

engine start, to wheels up, to ingress and egress, and return to base. Facility integration with the aircraft system to conduct each of these functions has proven to be quite the engineering challenge.

About the Aircraft

The 2AA:0001 aircraft is structurally non-representative of the final SDD aircraft design. It is, however, very representative from a systems perspective. Some of the features of the JSF air vehicle include a glass cockpit, an advanced fly-by-wire closed loop flight control system, 270 volts direct current (VDC) electrohydrostatic actuators (EHA) to drive control surfaces, an integrated power and thermal management system, and a 40,000-pound thrust-class F135 engine. EHAs provide the mechanical power to position the flight control surfaces. There is one EHA driving each flight control surface. For critical surfaces (Horizontal Tail and Flaperons), dual-tandem EHAs provide redundant actuation within a single line replaceable component.

The electrical power system provides the generation, distribution, control, and protection of electrical power for various utilizing equipment. Where required, dedicated and redundant power is provided for flight critical systems or components. A unique

feature of the system is the use of an Engine Starter/Generator (ES/G) system. The ES/G system serves a dual purpose in that it provides the rotational torque to start the main aircraft engine as well as the primary electrical 270VDC power generation.

The Power and Thermal Management System (PTMS) includes the equipment necessary to provide aircraft main engine start, auxiliary power, cockpit cooling and pressurization, avionics cooling, mechanical equipment thermal management, and pressurized air for the On Board Oxygen Generation System (OBOGS) and the On Board Inert Gas Generation System (OBIGGS).

The JSF Vehicle Systems Processing (VSP) architecture provides a generic processing and communications infrastructure used to implement certain functions of the aircraft Flight Control Systems (FCS), Propulsion system, Vehicle Systems (VS) Prognostics and Health Management (PHM), and Utilities and Subsystems (U&S). The VSP infrastructure is composed of the following components—► Vehicle Management Computer (VMC). The VMC provides a triplex computing environment with an Open System Architecture (OSA) hardware design.

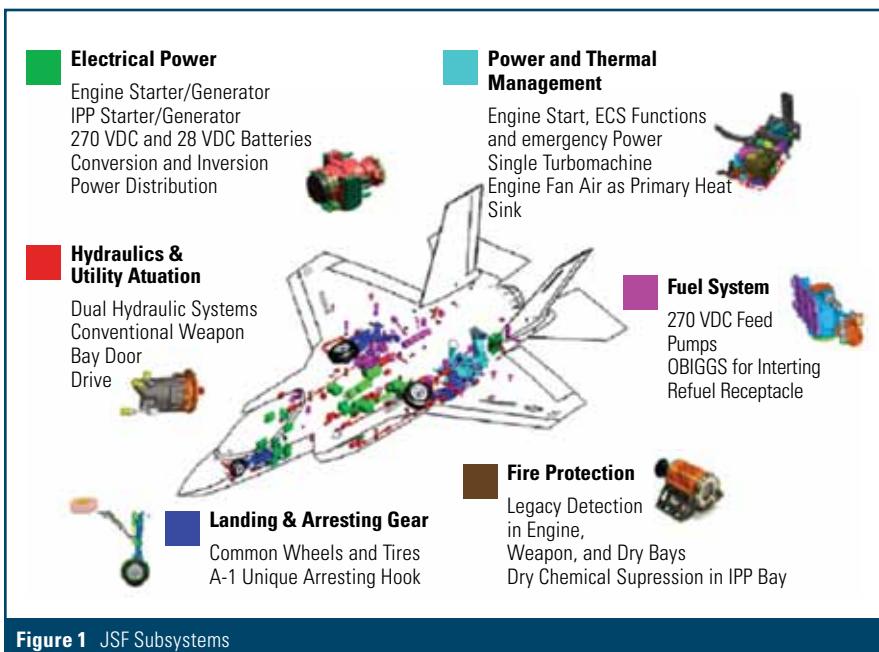


Figure 1 JSF Subsystems

- VMC Software Execution Platform (SEP). The VMC SEP includes the Vehicle System Software Execution Platform (VSEP) middleware, a Lockheed Martin (LM)-developed operating system (OS), and various low-level Board Support Packages (BSP).
- Vehicle System Network (VSN). This triplex serial data bus facilitates transmission of data to and from aircraft subsystems controlled by VSP, with adequate data rates for control, data recording, and PHM applications. A Common Serial Bus Interface Unit (CSBIU) is incorporated in each networked unit to enable network communications.
- Remote Input/Output (RIO) Units. RIO Units provide local analog and discrete interfaces to subsystems for which a serial bus interface is not economical.
- Network Daughter Board (NDB). The NDB provides an interface to the VSN IEEE-1394b-2002 high-speed serial data network.

Test Objectives. The primary objective of this test series is to evaluate battle damage effects on the F-35 FCS. Testing will include the effects of damage directly to FCS components, the electrical power system, and component communication through the vehicle systems components. A key part of this test will be determining the synergistic effect that damage to one subsystem has on other reliant subsystems. Secondary objectives include the effects of fire, fuel migration, and pilot escape capability.

Specific test results will be further evaluated with pilot-in-the-loop simulations of damaged aircraft characteristics by replicating, to the extent possible, ballistic test damage effects in LM Aero JSF aircraft

simulators (Vehicle Integration Facility [VIF] and Vehicle System Integration Facility [VSIF]).

Aircraft Integration with Test Facility

Integration of 2AA:0001 will be the most complex ever conducted for a Live Fire Test at the Weapons Survivability Lab and requires a significant amount of support and coordination between government test team and LM (Vulnerability, Integrated Test Force, and subject matter experts) assisting with the definition of the system interfaces, capabilities, and limitations. Integrating a test control concept to remotely control this advanced aircraft has led to several innovative test integration schemes. The JSF aircraft will be remotely controlled by interfacing with the aircraft's 1394 data bus and by providing remote control of cockpit switches (Figure 2). By interfacing with the aircraft's 1394 data buses, the Test Control Graphical User Interface (GUI) provides commands to the VMCs to control the throttle and control surface positions. A Cockpit Remote Interface System will remotely control the required cockpit switches

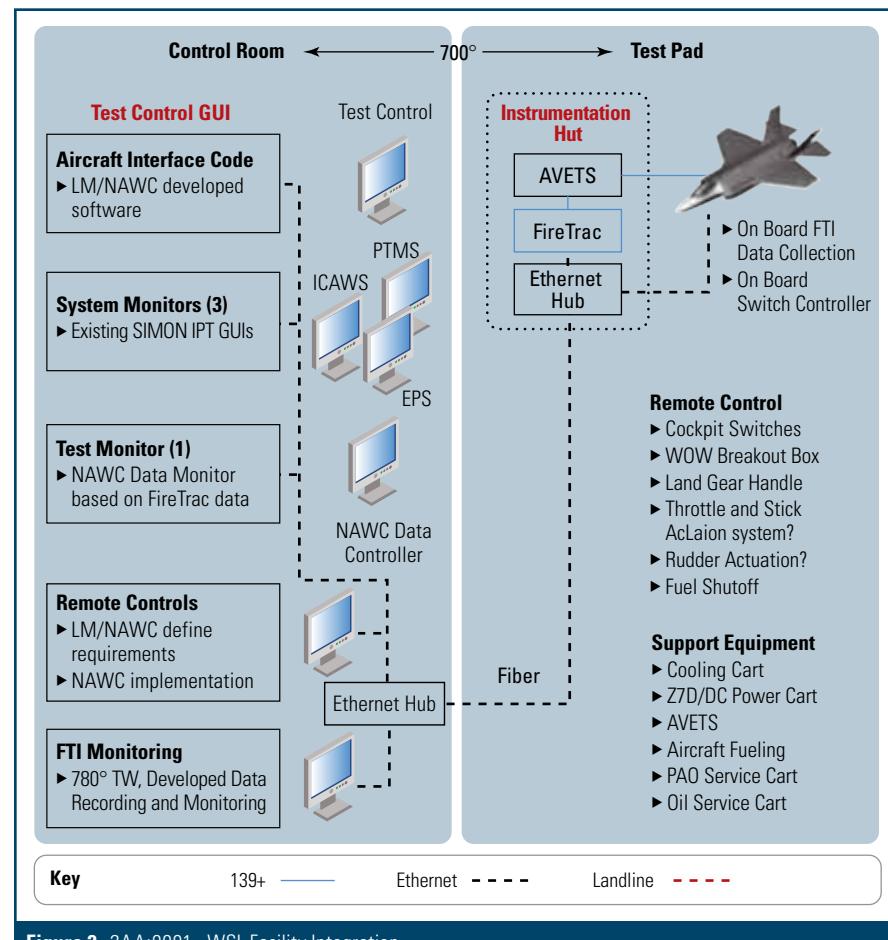


Figure 2 2AA:0001 - WSL Facility Integration

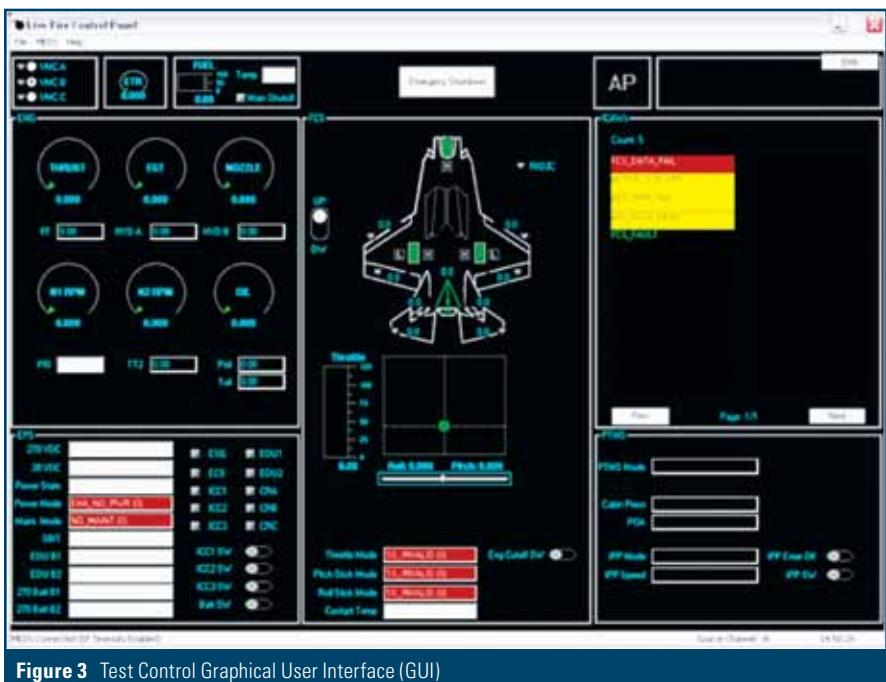


Figure 3 Test Control Graphical User Interface (GUI)

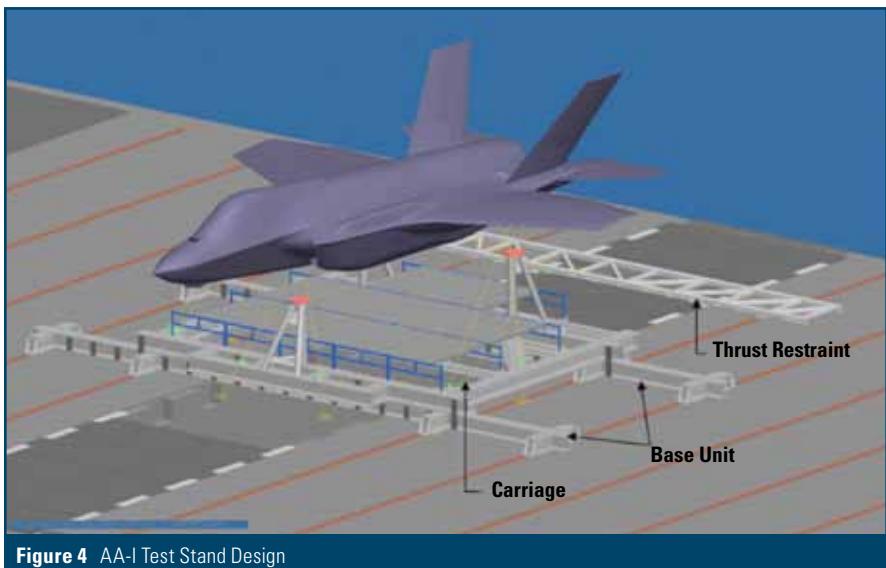


Figure 4 AA-I Test Stand Design

for normal aircraft operation from the control room. The control room will have almost everything that the pilot would see and control during a flight during the ballistic testing. To monitor specific parameters of the systems being tested, three additional subsystem GUIs will be available to test engineers.

Two systems will be used for data collection—one for recording the 1394 bus traffic and one to record available flight test instrumentation. NAWC is developing the capability to stream 1394 messages to a data collection system for playback and post-test analysis. This system is based on DapTechnology's FireTrac IEEE 1394b Test & Simulation Platform using the

latest technology 1394b for real-time data recording. To record aircraft flight test instrumentation parameters, NAWC has teamed with the 780th Test Squadron to develop a data collection system based on National Instruments PXI chassis and LabView. This system will be mounted in the aircraft and provide a capability to record approximately 250 channels of data and provide data-monitoring capability in the control room.

The aircraft will be remotely controlled by the test personnel. Aircraft control will be accomplished by the use of 1) an Air Vehicle Engineering Test Set (AVETS) that is coupled to the Vehicle System Network of the aircraft via an

IEEE-1394b-2002 signal bus connection on the Maintenance Interface Panel (MIP), 2) a weight-on-wheels/weight-off-wheels breakout box, and 3) actuators in the cockpit to press/throw cockpit switches and to move the side stick, and throttle. Control surface position will be commanded by running scripts that represent several evasive maneuvers. Surface positions and control surface movement rates were recorded during pilot-in-the-loop simulations. Scripts were defined to replicate surface position and rates.

Testing will be conducted on the Live Fire Test pad at the Weapons Survivability Lab, China Lake, CA. The LFT site is the home of a new nine-engine High Velocity Airflow System (HIVAS). The airplane will be mounted on a test fixture composed of a base unit and carriage stand. The base unit is used to take the aircraft thrust and aerodynamic loads and distribute them in to the test pad at specific tie-down locations (Figure 4). The carriage interfaces with the aircraft at three jack-point locations and uses tie-down cables to hold the airplane in position. The carriage will translate over a tunnel integrated into the LFT pad to accommodate the various shotlines. A thrust restraint is used to react engine thrust loads up to MAX augmented thrust.

Test Approach

Testing will be conducted in a manner that will maximize the number of shots achieved on the test article. Early in the test series, the aircraft will be reconstituted between test shots.

Wiring harnesses that route power and signals between the electrical power system components and/or flight control system components will be tested and repaired before testing individual components. Given the importance of the Integrated Power Package (IPP), the PTMS and the engine with regard to meeting test objectives, shielding will be used to minimize collateral damage to these systems.

The effects of dry bay fires on flight critical equipment will be evaluated as part of the LFT, but dry bay fires will not be permitted to destroy the aircraft. CO₂ will be ported into the aircraft at multiple locations for the purpose of extinguishing dry bay fires after flight critical equipment evaluations are completed. Test instrumentation (internal video, thermocouples) will be



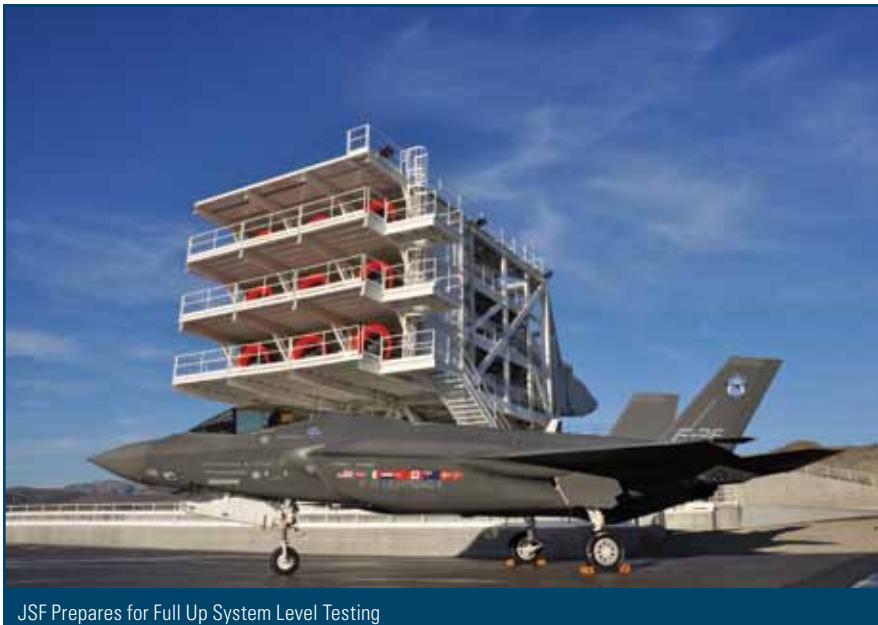
Figure 5 JSF MANPADS Layout

used to allow test engineers to determine when to activate the CO₂ fire extinguishing system. Engineering analysis and judgment will be used to estimate the longer term effects of dry bay fires on flight-critical equipment.

2AA:0001 will require several months of preparation and checkout prior to test. Ballistic testing is currently scheduled to begin early summer 2010.

Following the conclusion of ballistic testing, analysis of the test data will enable the Vulnerability Team to select six battle damage scenarios for the purpose of conducting six pilot-in-the-loop aircraft handling characteristic evaluations at the LM VIF or the VSIF. The objective of the pilot-in-the-loop evaluations is to replicate to the extent practical the real-world ballistic damage

and system-level response of the aircraft in the VIF/VSIF to ascertain pilot-in-the-loop post-damage flight characteristics of the aircraft. General procedures to conduct the aircraft handling evaluations will be identical to those used for XG-SV-LF-07C (Flight Control Vehicle System Integration Facility Test). For each of the six evaluations, the specific procedures to inject the battle damage scenario into the VIF/VSIF will be coordinated with subject matter experts of the affected systems, the VIF/VSIF operators, and the Vulnerability Team. ■



JSF Prepares for Full Up System Level Testing

JSF Live Fire Test— Pilot-in the Loop Simulator Testing

by Jeffrey Andrus

The F-35 Joint Strike Fighter (JSF) program has taken a new approach to achieving a clearer understanding of the system's vulnerability while improving the efficiency of Live Fire Test and Evaluation (LFT&E) program. In a pioneering effort, the JSF LFT&E program implemented Man-in-the-Loop (MTL) simulator testing during the test series designated XG-SV-LF-07C (LF-07C.) The purpose of this test series was to examine the response of the pilot and F-35 aircraft to a series of failures that represent possible damage modes associated with encounters with ballistic threats.



The LF-07C testing was conducted under the direction of the Lockheed Martin (LM) vulnerability group at the Vehicle Systems Processing/Flight Control System Integration Facility (VIF) and the Vehicle Systems Integration Facility (VSIF) at in Ft. Worth, TX.

Testing the Integrated Design of F-35: LF-07C Test Motivation

The JSF LFT&E program is committed to verifying performance of the critical systems on the aircraft, evaluating the built-in redundancies, and understanding the interdependencies of integrated subsystems from a ballistic impact standpoint. Many questions arise concerning the reaction of complicated systems when impacted by ballistic penetrators, and the F-35 is no exception. The only feasible method (short of shooting a flying aircraft) is to use advanced flight simulation that either includes or models subsystem performance with a pilot at the controls.

Many F-35 critical subsystems are highly integrated. For example, the Power and Thermal Management System (PTMS)

and the Electrical Power System (EPS) are closely coupled within the Integrated Power Package (IPP); the electrically driven Flight Control System (FCS) is interdependent with the EPS. These are some of the critical subsystems that were tested during the LF-07C test series.

A key ingredient in understanding an aircraft's vulnerability is the pilot or operator's situational awareness; included in this is the pilot's ability to determine if the aircraft has been hit and what systems may have been compromised. In the few moments after damage, the pilot needs to determine if: 1) the aircraft is controllable, 2) it will stay that way, 3) he/she can get home, 4) he/she can complete the mission. A fundamental question that previous JSF testing has not answered is whether the pilot has sufficient information to make this assessment and information warning of impending catastrophic failures.

Flight Simulator Test Capabilities

The F-35 program developed several MTL simulation facilities for a variety of purposes, including pilot training, operational flight program (OFP) development, subsystem integration, missions systems integration, concept of operations (CONOPS) development, and combat evaluations. LF-07C made use of two of these facilities: the VIF and the VSIF. Both of these facilities utilize MTL, varying amounts of aircraft hardware, real aircraft OFPs, and software that simulates the flight environment. The result is a very realistic flight simulation that closely approximates a flying F-35.

During LF-07C testing, the VIF and VSIF represented a real-time, airplane-level response to specific ballistically representative interrogations. These two facilities provide integration of real aircraft hardware and aircraft OFPs with a simulated atmospheric environment. In an earlier LFT series, the LM vulnerability team conducted a wind tunnel test to evaluate F35 aerodynamic performance with partially or totally missing control surfaces. An aerodynamic model was developed to represent these conditions and was incorporated in the LF-07C test series. Both facilities had the unique ability to represent these control surface damage scenarios in the aerodynamic model; if a portion of the surface were to be blown off from ballistic impact, the aero model represented that.

The VSIF, having the most hardware in the loop, is the most difficult to operate, and so was used only when necessary. Consequently, most of the test cases were conducted in the VIF; the VSIF was necessary in nine of the cases where real hardware was required, such as electrohydraulic actuators (EHA), electronic units (EU), and converter/regulators (C/R.).

Figure 1 shows a functional diagram of the VSIF facility. The facility is equipped with dynamic electro-hydraulic actuator (EHA) load fixtures, drive stand, EPS, and cockpit rooms. Each room's level of integration is controlled by the VSIF control room. The control room is separated into three areas for each integrated product team (IPT)—FCS, EPS, and HUA. The “core” of the control room layout is a cluster in the

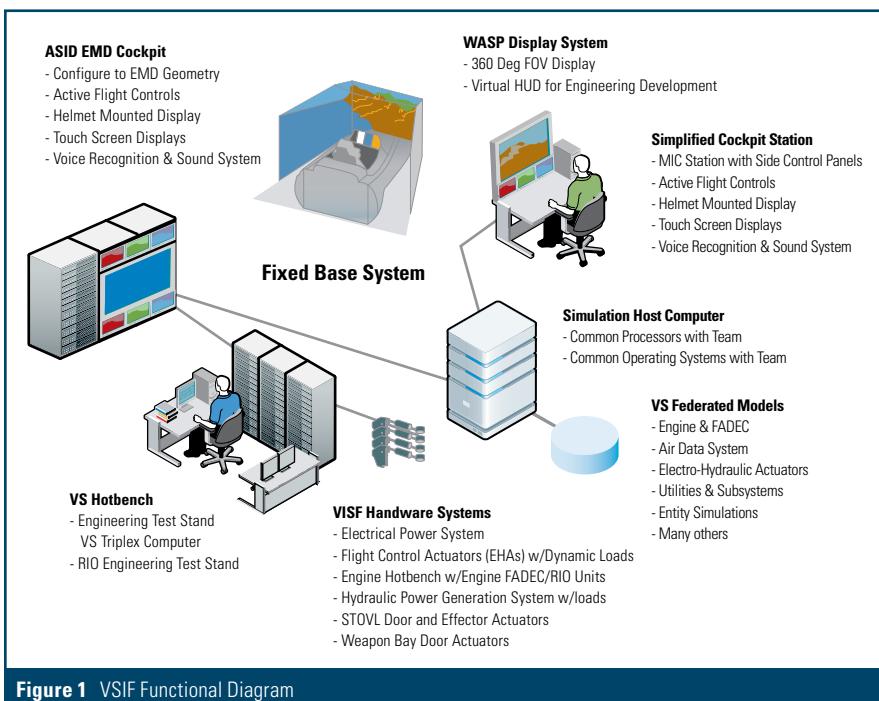


Figure 1 VSIF Functional Diagram

center of the room consisting of the Vehicle Management Computer (VMC) Engineering Test Station (VETS) and the Remote Input/Output (RIO) Engineering Test Station (RETS). In the center of this cluster is the VETS/RETS switch rack that allows the VSIF to switch from three standalone facilities to a single integrated facility.

The VIF system is similar to VSIF, but with less hardware in the loop; much of the actual hardware in the VSIF is emulated in the VIF. The VIF is divided into three system areas that consist of a motion base (MB) simulator, a fixed base (FB) simulator, and a VETS area. The remaining F-135 engine hotbench room, F-136 engine hotbench room, and display/conference room are ancillary to these areas. Only the FB VIF was used during the LF-07C tests.

Test Methodology

Before testing began, the F-35 Live Fire Team developed a list of test cases to be addressed. The criteria for defining required testing was based on issues identified in the *JSF Live Fire Test and Evaluation Master Plan*. The matrix of test cases was subsequently used to manage and address each question; each test case within the test matrix had a different objective with the overall objective of LF-07C to gather sufficient data to determine the response of production F-35 to failures that simulate combat damage to specific components on the aircraft.

Wherever possible, previously conducted failure mode and effect testing (FMET) was used to supply answers to some of the failure scenarios in the test matrix. Where no FMET series existed to address the question, a special live fire test case was developed.

A total of 40 different test cases were conducted as part of LF-07C, 31 that were common to all variants of the F-35, and nine that were unique to the short take-off vertical landing (STOVL) variant. Each test case was evaluated

against three different initial flight conditions, nominally with two iterations each—

- 20Kft, M0.8, straight and level flight
- 30° dive from 18,000 ft, M0.7 with 4-G pull-up to 15° (minimum altitude of about 2,000 ft @ M0.92)
- 20Kft, M0.8, 4-G wind-up turn

Each of the 31 common cases was judged on the basis of the following criteria—

- How well did the predictions for the results of the case match the data from the simulation event?
- Was the pilot given ample warning, and was he/she able to safely eject from the aircraft?
- Was the aircraft controllable such that the pilot could return to the forward line of threat (FLOT)? In other words, could the pilot control the aircraft enough to change direction and maintain altitude?
- Was it possible to conduct evasive maneuvering if required for survival?
- Was it possible to land the aircraft? In most cases, the actual landing was not attempted (due to time and expense), but a judgment call was made based on the nature of the failure and the handling qualities.

The STOVL-unique cases were similar, but refined slightly to adequately capture various landing procedures associated with a STOVL aircraft—

- How well did the predictions for the results of the case match the data from the simulation event?

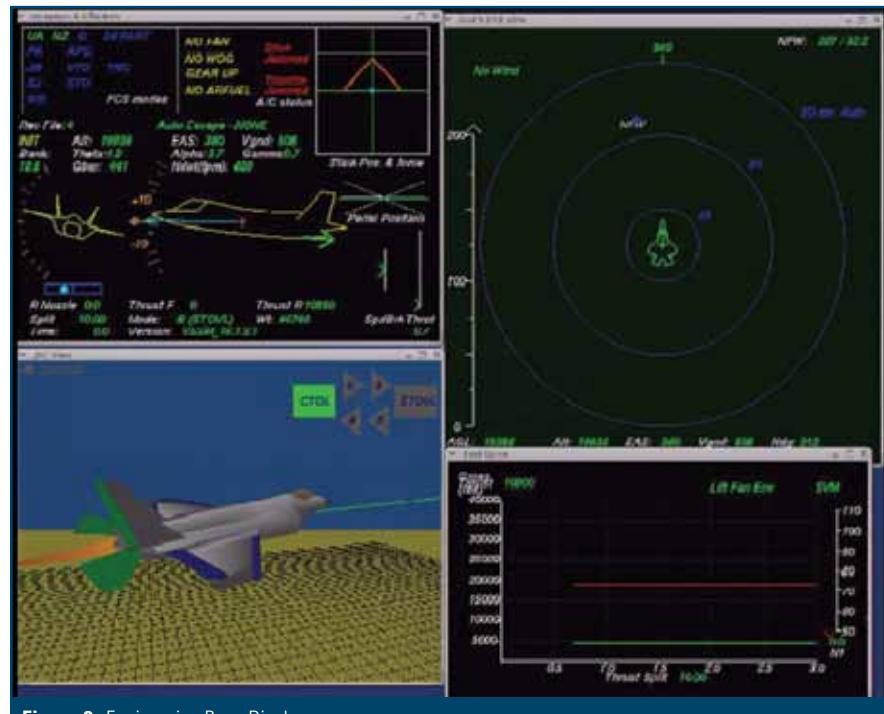


Figure 2 Engineering Page Display

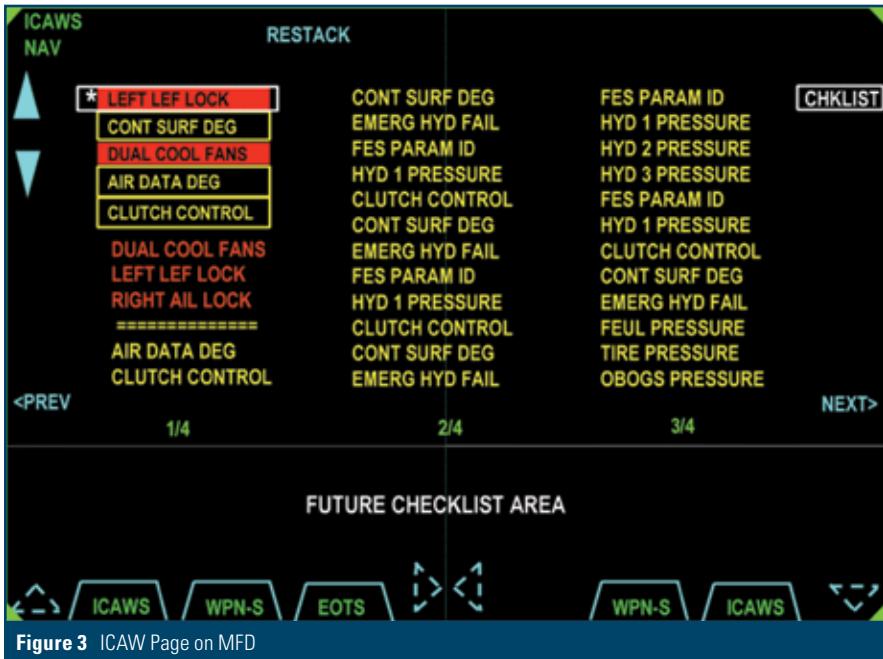


Figure 3 ICAW Page on MFD

- Was the pilot given timely warning, and was he/she able to safely eject from the aircraft?
- Was a conventional landing possible?
- Was a rolling vertical (short) landing possible?
- Was a vertical landing possible?

Conventional, rolling vertical, and vertical landings were not attempted in every test case. A landing attempt depended on the handling qualities reported by the pilot and the nature of the failures inserted. Where there was a question on the capability, a landing was attempted. The pilot used the Cooper-Harper Handling Qualities Rating Scale to quantify aircraft handling during and after each test case.

Recorded Data

Each event in the VIF and VSIF was documented by visual records as well as digital data recorded as a function of time. The visual records consisted of videos of the pilot “Heads-Up” display (HUD), the Left Multi-Function Display (MFD), and the Engineering Page, a screen set up to capture pertinent information in a graphical format. Audio data from each event was combined with the Engineering Page and was found to be very helpful in recalling critical information concerning the event.

Integrated Cautions, Advisories, Warnings (ICAW) as seen on the MFD were recorded. In addition to the visual records, digital data was recorded from the VIF and VSIF. This “DREC” file contains hundreds of parameters, recorded many times per second.

Selected parameters from the BUS traffic recorded in the DREC files included the FCS surface positions (commanded and actual), flight parameters found on the HUD, and some specific parameters for each test case.

Test Conclusions

The team conducted and documented the results of the 40 test cases, a total of 213 simulation runs during LF-07C. In addition, 20 FMET cases were documented in order to answer specific issues. Another 49 test cases were examined and addressed based on similarity with other tests. Archived data include video records and digital data files of each event.

Test results were compared to predictions. From the 40 test cases, predictions matched 26 times, or 65% of the time. There were 11 cases (27.5%) where pre-test predictions were more conservative than the tests. In other words, where an undesirable event was predicted, the aircraft turned out to be more capable than predicted. In three cases (7.5%), pre-test predictions assumed more capability than the aircraft had. All cases where the predictions did not match the test will be further analyzed for potential changes to future vulnerability analyses.

Results from LF-07C testing were used in refining the test matrix for the upcoming LF-19D full-up system level (FUSL) testing on an F-35 aircraft. FCS data recorded during simulator testing, in particular during pilot’s reaction to simulated threat engagements, provides

the basis for the flight test “scripts” that will be run during and after actual ballistic impact on the FUSL test article. Real control surface load data, as recorded in the simulator, has dictated the appropriate structural loading for the control surface structural shot in LF-19D. LF-19D will close the loop in regard to matching ballistic damage to the scenarios conducted in LF-07C. If the aircraft subsystems respond differently from ballistic impact, these damage scenarios will be retested in the simulator to provide the complete aircraft response.

STOVL results from LF-07C refined the test matrix for the upcoming STOVL Propulsion System Live Fire Testing (LF-19C.) STOVL simulations showed the STOVL propulsion system to be tolerant of minor changes in roll post thrust due to damage on one side of the aircraft. This eliminated the need to conduct testing that would yield similar results.

The use of MTL simulator testing at this stage in the test program has proved valuable as the JSF Live Fire Team starts a complex and thorough test program for the three F-35 variants. Simulator testing examines the response of the pilot and F-35 aircraft to failures that represent possible damage modes associated with encounters with ballistic threats. This objective would not be achievable in a purely ballistic test environment, whether it be from cost limitations, limited test article lifespan (a full-up test article can only be “full-up” for so many shots), or pilot exposure to ballistic threats. The LF-07C testing also identified the best candidate test points on very expensive and complex test articles. ■

One-of-a-Kind Testing at NAWCWD Means More Survivable Aircraft

by Renee Hatcher

The Naval Air Warfare Center Weapons Division Weapons (NAWCWD) Survivability Lab at China Lake recently developed and verified the capability to accurately and realistically test, evaluate, and document the effects of a Man Portable Air Defense System (MANPADS) impact on aircraft in an effort to make them more survivable. This capability is unique to China Lake, and is known as the Missile Engagement Threat Simulator (METS).

"Our ultimate goal is to make sure the pilot completes the mission and returns home safely," said Ronnie Schiller, METS project manager.

MANPADS are shoulder-launched missile systems produced by more than 25 countries. MANPADS are relatively inexpensive and widely available to the world, making them a serious threat to US and allied aircraft. METS will play an important role in developing a strategy to severely lessen MANPADS effectiveness by accurately simulating an impact and collecting the necessary data to help predict the vulnerability of aircraft.

For the last 20 years, Congress has mandated that new aircraft acquisition programs undergo realistic vulnerability testing before entering low rate initial production. METS was developed at China Lake to help aircraft acquisition programs comply with the Live Fire Test Law by providing a method of effectively evaluating an aircraft's ability to tolerate MANPADS.

"There has been a long chain of challenges throughout this project over the last 15 years," said Robert Gerber, lead mechanical engineer, "with over 70 individuals contributing with very unique solutions. We have come a long way since the early days of black smoke and mangled missile debris exiting the barrel."

There are three components of METS. First is the portable, six-inch, high-pressure gas gun.

The gas gun provides for a mix of interchangeable barrel lengths and chamber volumes to achieve the desired acceleration profile. For example, a hovering helicopter requires a higher acceleration profile than a tail-chase fighter engagement due to the relative velocity between the MANPADS and the aircraft.

Second is the MANPADS itself. METS uses an actual MANPADS with two minor modifications to the fuze and fins. The foreign fuze is replaced with an exploding bridge wire fuze. The fins

are replaced with retractable versions that expand once the MANPADS exits the barrel.

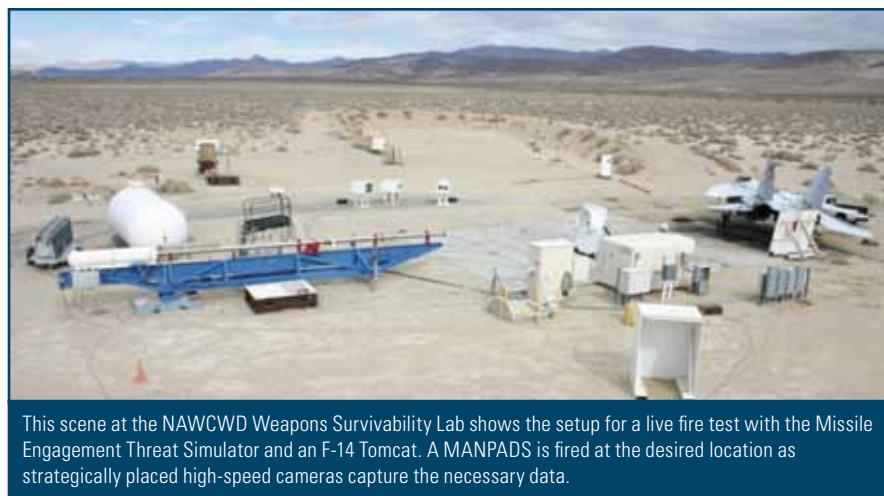
Third are the screens placed near the target. When the fins contact the charge screens, the current is transferred to the exploding bridge wire fuze which in turn detonates the warhead. Different MANPADS provide for different fuze timings. By varying the charge screen location, METS has the flexibility to simulate a proximity, contact, or delayed impact detonation.

"There's no other facility to conduct MANPADS testing in a realistic engagement scenario to the fidelity that we can achieve here at China Lake," Schiller said.

The Weapons Survivability Lab conducted three fully configured METS tests in 2008. An F-14 Tomcat, an AH-1J Sea Cobra, and an F/A-18 Hornet have been tested. The Hornet test was the first test with a live MANPADS detonation on an operating aircraft, using realistic airflow and intercept velocities.

METS has several live fire test and evaluation (LFT&E) tests scheduled at China Lake in the coming years with the Joint Cargo Aircraft Program, Joint Aircraft Survivability Program/Joint Live Fire, and the Joint Strike Fighter Program.

Prior to METS, previous test methods included static warhead testing and free-flight testing, which were limited in producing and analyzing realistic conditions, and provided inadequate data collection. Static warhead testing does not account for the kinetic energy component of damage, which can be significant. Free-flight testing limitations include the lack of external airflow,



This scene at the NAWCWD Weapons Survivability Lab shows the setup for a live fire test with the Missile Engagement Threat Simulator and an F-14 Tomcat. A MANPADS is fired at the desired location as strategically placed high-speed cameras capture the necessary data.



An F-18 is hidden behind this explosion during the first live MANPADS launch using an operating aircraft with realistic intercept velocity, and realistic airflow provided by the Weapons Survivability Lab's High-Velocity Airflow System at NAWCWD China Lake.



In the 15 years since the beginning of Missile Engagement Threat Simulator work at the NAWCWD Weapons Survivability Lab, more than 100 people have supported the project.

exaggerated impact velocities, and targeting difficulties. METS addresses all these limitations to create a significantly more realistic test scenario.

"To have the capability to repeatedly and reliably throw these weapons at our aircraft, target a certain area, and capture the data is a big deal," said Chuck Frankenberger, Joint Strike Fighter vulnerability LFT&E lead. "We use the data to validate our aircraft vulnerability assessments. MANPADS

are one of the threats we assess against. If there is a significant difference between our models and the tests, there could be a design change in the aircraft."

One challenge for the METS team is that it has to deal with constantly evolving threats.

"What we hope to build here is an arsenal of all the different types of weapons that could be used against US or allied aircraft," said Jay Kovar, head of the Vulnerability Branch. "METS is going to be a key tool that provides us the capability to evaluate aircraft against the emerging MANPADS threat." ■

Reference

1. "One-of-a-Kind Testing at NAWCWD Means More Survivable Aircraft: Press Release." China Lake 25 Feb 2009.



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Arcing Survivability

by Colin McCabe and Patrick O'Connell

Fire represents a significant vulnerability to all air vehicle systems. Combat aircraft in particular are at risk due to the potential to encounter enemy threats that can ignite flammable fluids, including the onboard fuel, which can represent a significant portion of the aircraft's internal volume. These threats can either directly ignite a fire due to their own energy, or indirectly contribute to fire ignition when the threat penetrates another potential ignition source. One secondary ignition source is damaged aircraft electrical wiring, which can cause electrical arcing. This arcing can occur in the vicinity of leaking fuel components also penetrated by the threat. The F-35 Joint Strike Fighter (JSF) Live Fire Test & Evaluation (LFT&E) program recently conducted a project to examine the contribution of electrical arcing to fire ignition. A total of 298 tests were conducted during this test series.

The purpose of this test series was to evaluate aircraft vulnerability to potential electrical arcing and fire ignition hazards associated with its electrical system. The JSF weapon system employs 28 direct current volt (VDC) and 115 alternating current volt (VAC) circuits, as well as a 270 VDC power system that will be used to operate electro-hydrostatic control surface actuators. The electrical system also contains a variety of protective devices, collectively called Over-Current Protection Devices (OCPD). These devices were examined in this program for their potential to reduce fire vulnerability.

Testing for this test series, designated Live Fire Test #06 (LF-06) by the JSF Program Office (JSFPO), was conducted under direction of the US Air Force 46th Test Wing, 780th Test Squadron, Aerospace Survivability and Safety Operating Location (780 TS/OL-AC). Testing was conducted at the Aerospace Vehicle Survivability Facility (AVSF) at Wright-Patterson Air Force Base, OH.

Effect of Altitude on Arcing

One objective of the project was to explore the role that altitude plays in promoting the occurrence of electrical arcing events, as well as the effect that altitude has on fire ignition/sustainment from these arcing events. In theory, and in some physical circumstances, altitude could affect arc size, intensity, and

potential for fire ignition/sustainment. The test article incorporated a vacuum chamber to simulate testing from sea level (~14.7 pounds per square inch [psi]) to an altitude of 30,000 feet (~4.3 psi). The fuel spray was provided by an oil burner nozzle that produced a finely atomized fuel spray spread over a 70-degree cone, which moved at low velocity. Figure 1 shows the test setup within the vacuum chamber.

Results of the testing indicated that current density (affected by both voltage and wire gauge) had a larger effect on fire ignition/sustainment

results than altitude. Within this set of test conditions, the only differences caused by ignition at altitude versus ignition at sea level were observed in the physical appearance of the flame front propagation during the early stages of ignition. Once a sustainable fire was fully developed, the flame was generally more diffuse in conditions simulating altitude. There was no observable difference in the likelihood of a fire ignition; therefore testing simulating a higher altitude was discontinued. Example flame images at sea level and 30,000 feet are shown in Figure 2.

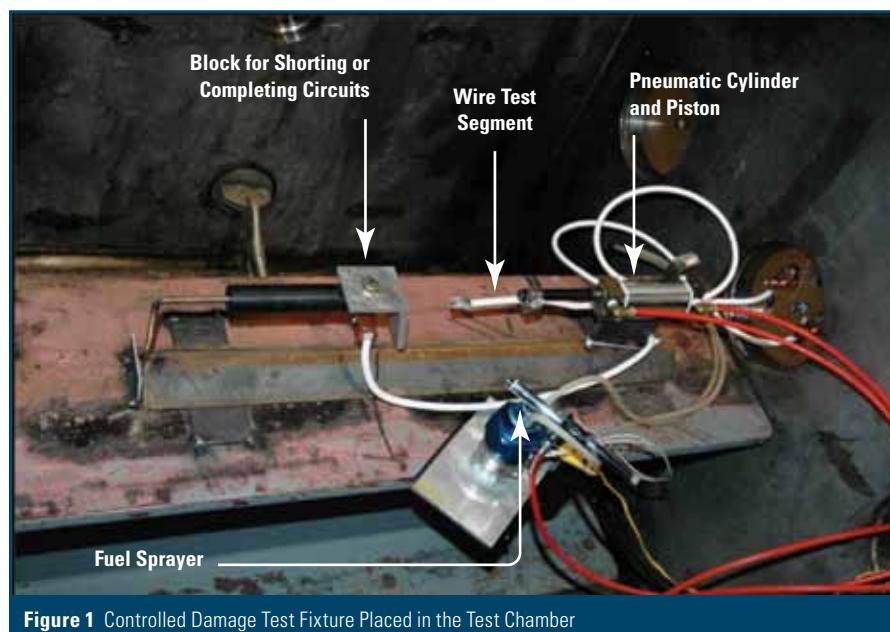


Figure 1 Controlled Damage Test Fixture Placed in the Test Chamber

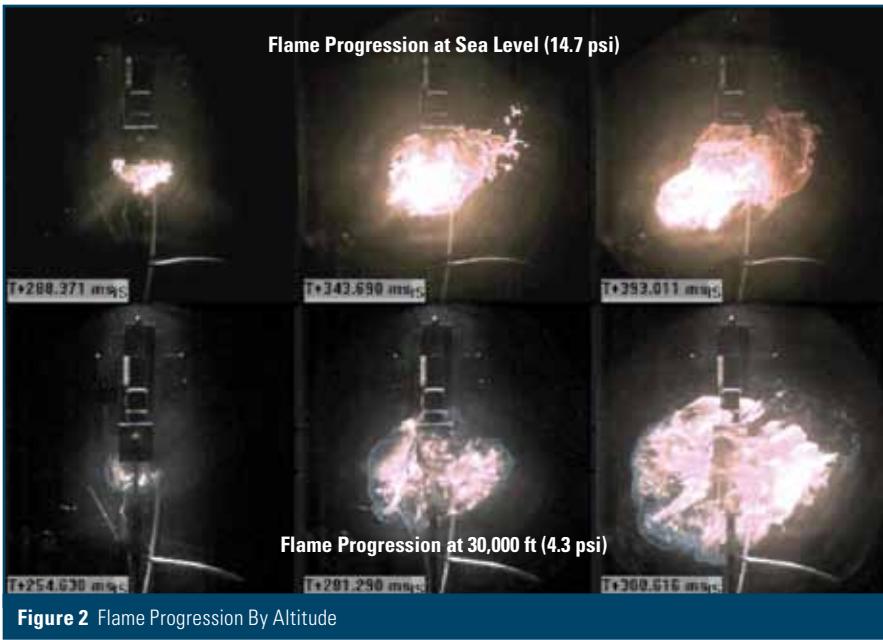


Figure 2 Flame Progression By Altitude

Controlled Damage Testing

Controlled damage testing was conducted to determine the likelihood of initiating a fire for various voltage/amperage/damage combinations under favorable fire conditions, and to provide a baseline for comparison with ballistic damage tests. Testing was divided into three categories: 1) short circuit, 2) separating arc gap, and 3) 90% conductor diameter reduction. The performance of the OCPDs was also evaluated during the damage events.

The short circuit tests were accomplished by causing a short to ground in a circuit which, up to that moment, was energized and operating normally. This was accomplished by

moving an exposed conductor from a wire segment into contact with a grounded plate. The separating arc gap test condition was accomplished by causing a break in an active circuit by separating the conductor from a grounded plate. The partial diameter loss tests were accomplished by diverting current from a healthy circuit onto one in which 90% of a test segment's diameter had been removed. In each test condition, Jet Propellant 8 (JP-8) fuel spray was directed at the region of interest from a distance of about six inches. An example of the formation of a sustained fire caused by one of these damage conditions is shown in Figure 3.

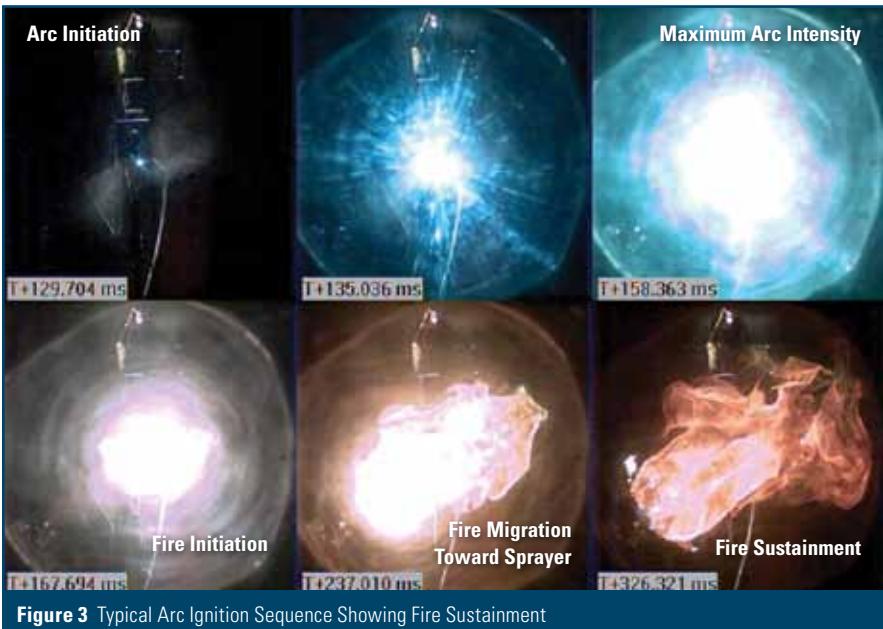


Figure 3 Typical Arc Ignition Sequence Showing Fire Sustainment

In controlled damage studies, the most likely form of damage to cause electrical arcing was a dynamic separation. The least likely form of damage to cause electrical arcing was the conductor diameter reduction. No overheating or catastrophic damage resulted from manually removing 90% of the diameter of the wires tested. It was reasoned to be extremely unlikely that a ballistic event could result in a percentage removal greater than 90% without entirely severing the wire, so 90% removal was considered worst case. In general, for the controlled damage conditions, as the total available power increased, so did the likelihood of initiating a sustained fire.

Ballistic Testing

Ballistic testing was conducted using both single wire and wire bundle configurations. Threats involved steel cubes which simulated missile warhead fragments. The single wire and wire bundle ballistic tests had multiple purposes: 1) to evaluate the possibility that an electrical arc caused by ballistic damage may start a dry bay fire in the presence of fuel; 2) to evaluate the performance of the circuit protection devices in preventing a dry bay fire due to ballistic threat damage; specifically for wire bundles containing communication wires; and 3) to examine possible interference and cross-over voltage issues introduced with a ballistic impact.

Testing for each configuration was first conducted with the wires in the presence of a fuel spray. For the wire bundle configuration, some tests were also conducted with the wires in the presence of a fuel tank. The fuel spray utilized was identical to the controlled damage tests. The fuel tank tests incorporated a production-representative tank configuration. All test configurations were evaluated with OCPD protection.

In ballistic damage tests, there were three main mechanisms that caused arcing: 1) ballistic damage, particularly of heavier gauge wires, creating exposed frayed ends, which can easily short against grounded surfaces; 2) ballistic damage of power bundles, which does not necessarily sever or open the bundle, but allows cross-over arcing between wires (from higher voltage/amperage to lower voltage/amperage combinations); and 3) ballistic damage

to bundles containing metallic mesh over-braid, which allowed shorting from current carrying wire to the over-braiding.

Results from the single-wire ballistic testing suggest that shorting events due to arcing appear to be more likely for lower momentum impacts when compared to higher momentum impacts, based upon the observed damage. For lower momentum fragments and heavier gage wires, the potential for cross-over or shorting from frayed wire ends increased. Electrical arcing events were limited to shorting against ground in a few tests, and two tests where separation arcing occurred. No single wire ballistic tests ignited or sustained a fire due to electrical arcing.

Two different types of wire bundles were tested: bundles consisting of wiring representing communication/control systems and bundles that contained wiring used for power transmission. In communication/control bundle tests, OCPD trips were observed when the metal mesh over-braiding connected to a common ground (as designed). Cross-over arcing was also observed in a few events. These arcing events were small (of barely discernable intensity) and brief, sometimes occurring with a significant delay after impact. For communication/control bundles, impacts by fragments of larger momentum tended to sever the bundles.

Powered wire bundles were also tested. Ballistic impacts on the bundle tended to produce an impact flash capable of igniting the fuel spray in the immediate vicinity. Many of the ballistic tests on power bundles resulted in sustained fires either from shorting to ground on the test fixture or from cross-over arcing between wires within the bundle. In one instance, arcing to ground and cross-over arcing between the wires continued for more than 11 seconds. In this test event, a very exothermic and long-lasting cross-over arcing event occurred.

Like single wire testing, wire bundle testing demonstrated that a fragment with lower momentum had a higher likelihood of causing electrical arcing than did one of greater momentum. Less damage and recoil increased the possibility that damaged wire segments would interact.

Unprotected versus Protected Circuits

Generally, the only damage condition that allowed OCPDs to react was the short circuit condition. Within the short circuit condition, there were actually two possible failure modes: shorting to ground (*i.e.*, dead short) and cross-over shorting between wires in a wire bundle.

It was apparent that some OCPDs do provide some added fire protection against fire ignition initiated from electrical arcing. This was most evident during controlled damage tests, particularly involving low amperage 270 VDC circuits; however, the only circumstance in which any OCPD may provide protection is in the case of a short circuit. The OCPDs demonstrated that they may trip if a short circuit occurs; however, they did not always do so. Some devices were quite effective in suppressing fires during controlled damage short circuits, while others were not particularly effective.

The OCPDs only reacted to ballistic impacts in cases where the internal metal over-braid of the wire was grounded. In such cases, the OCPDs tripped in reaction to the shorted circuit. In cases where cross-over arcing occurred between wires, the peak current was limited from achieving the high amperages needed to trip the OCPDs in a timely fashion. As a result of this, arcing could continue unabated.

Controlled Damage Arc Analysis Method

An analysis methodology was developed to estimate the amount of energy present in each of the electrical arcs observed in controlled damage testing. Initially, in the test planning phases of this program, determination of instantaneous energy available in the arc was the primary factor of concern. Evidence gained in testing indicates that energy distribution was also an important factor.

Estimates of energy density allowed the construction of a graphical representation with which to view the occurrences of a sustained fire and electric arc energy against any number of variables, including electrical fault scenarios, circuit descriptions and values, protection methods, and protection behaviors. The analysis was helpful in determining an important energy density value for this setup. The results of this analysis appear to be of future value as a basis for continued

analysis of the physics of fire ignition from electrical arcing, including the amount of energy actually required to ignite a JP-8 spray. This in turn could be useful in vulnerability and fire prediction modeling. ■

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Excellence in Survivability— Robert E. Walther

by Eric Edwards

The Joint Aircraft Survivability Program Office is pleased to recognize Mr. Robert E. Walther for Excellence in Survivability. With more than 50 years of Department of Defense (DoD) experience—including work as a Navy officer, Army civilian, and contractor—Bob has played a significant role in testing and analyzing the survivability/lethality of numerous combat systems. In particular, his work has impacted nearly every major US combat helicopter (and many fixed-wing and foreign systems) in the skies today. Bob currently works for the SURVICE Engineering Company, supporting the Ballistics & NBC Division of the US Army Research Laboratory's (ARL) Survivability/Lethality Analysis Directorate at Aberdeen Proving Ground (APG), MD.



The son of a chemical engineer and elementary school teacher, Bob was born in Aruba, where his father was on assignment for the Standard Oil Company of New Jersey (SOCNJ). When Bob was two, the Walthers moved back to Westfield, NJ, where he recalls spending his youth involved in model airplanes and sports.

"I was particularly fascinated with the numbers in sports," Bob said. "In baseball, everything was so orderly: nine innings, three strikes, four balls, and three outs. I also learned how to figure batting averages and keep track of statistics." Little did he know that this early fascination with numbers would be instrumental in his eventual career in aviation analysis.

After high school graduation, Bob attended Colby College in Waterville, ME. There, he majored in mathematics, played football, and met his future wife, Cathy. In 1958, Bob had an especially big year, as he graduated from Colby, got married, and was accepted to the Navy's Officer Candidate School (OCS) in Newport, RI. After finishing OCS in May of 1959, he was assigned as the communications officer on the submarine tender USS Fulton, based in New London, CT.

"The highlight of my two years on the Fulton," Bob said, "was a goodwill trip to Scotland. The US was planning to establish a nuclear sub base there, and our job was to check out the harbor at Holy Loch and show the local population what nice people US Sailors were."

When his tour of duty on the Fulton ended, Bob was assigned to the Navy's Nuclear Power School (NPS) in Groton, CT, where he began teaching introductory math and physics. "I thoroughly enjoyed my experience at the NPS," Bob said, "and for a while, I even considered teaching as a career." But Bob's career path would soon change when the Navy decided to move the NPS to Bainbridge, MD, just a few miles down the road from APG. Although he didn't realize it then, the Navy man was about to become an Army man.

Upon Bob's arrival in Maryland, he had the opportunity to take some college courses offered at the US Army's Ballistic Research Laboratory

(BRL)—now ARL—at APG. There, he met Lt. Harold Breaux (who would later become the Chief of BRL's computing lab). Through Breaux's encouragement, Bob was hired as a mathematician in BRL's Aircraft Weapons and Vulnerability Branch. "This branch had an outstanding group of people," Bob said, "including some of the pioneers of aircraft survivability. They included Roland Bernier, Jim Foulk, Walt Thompson, Walt Vikestad, and Don Mowrer. This was the group that really shaped my future."

Bob also cites numerous others who were particularly influential to him during his 36 years of civilian service at BRL/ARL. They include Don Haskell, Mike Vogel, Steve Polyak, Lex Morrissey, Dennis Bely, and Bob Mayerhofer. In particular, Mayerhofer and Walther (or "Bob and Bob," as they were sometimes called) worked together on many projects. "We had an especially good relationship," Bob said, "and we always just kind of meshed in our philosophy of vulnerability assessment."

Bob's primary responsibility during his civilian service was performing vulnerability studies involving aircraft, especially helicopters. And there is hardly a US combat helicopter that Bob's work didn't touch, including (along with many variants) the UH-1, AH-1, OH-6, UH-60, CH-47, OH-58, AH-64, RAH-66, and ARH-70. Likewise, Bob was involved in analyzing numerous missile, fixed-wing, and foreign system programs (often from a lethality perspective).

In the 1960s, Bob helped to identify an important need to expand helicopter vulnerability analyses and include more flight profiles. He recognized that analyses should not just focus on an aircraft in forward flight mode (the traditional profile), but they should also consider an aircraft in hover mode. He also advanced the idea of dividing analyses into different flight categories—such as high and slow, low and slow, high and fast, and low and fast. Although these ideas are accepted as standard practice today, they were very much novel concepts at the time.

In addition, in the '80s and '90s, Bob helped to develop an aircrew vulnerability assessment input model, which combined computer-generated incapacitation (ComputerMan) data with pilot survey information to produce aircrew damage (Pcd/h) and kill (Pk/cd) probability input data. He also supported an important Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) test program that analyzed combined blast and fragment effects against aluminum and steel spaced plates. The results from this study continue to have application for a wide range of aircraft vulnerability programs.

"I think I've always tried to be an innovator, and improve any processes I could," Bob said. Perhaps his most notable innovation came when he was asked to create and implement a "quick response" analytical model to assess the vulnerability of aircraft to high-explosive incendiary projectiles when a computer-modeled target description was not available. This model, which was developed with the help of Mike Vogel, became known as the Personal Computer Assisted Vulnerability Analysis Method (PCAVAM).

"I guess PCAVAM is the accomplishment I'm most proud of," Bob said. "It made the process a lot more efficient, as opposed to the old paper-and-pencil, back-of-the-envelope method. And its various applications, techniques, and criteria are still relied on today."

Bob's other significant accomplishments during his government career include participating on source selection boards for the Utility Tactical Transport Aircraft System (i.e., the Black Hawk) and the Advanced Attack Helicopter (i.e., the Apache), analyzing Vietnam era combat

data, supporting numerous JTCG-related tasks, and performing a wide range of Joint Live Fire (JLF) pre-shot predictions and post-test analyses.

Bob also has authored or co-authored more than 50 technical reports, including several landmark multi-volume ARL methodology reports that have had influence across the aircraft survivability discipline. And he has been the recipient of numerous achievement awards, including the Department of the Army Superior Civilian Service Award.

Although Bob's retirement in 2000 signified the end of his civilian service, it did not signify the end of his days at ARL or of the aircraft studies he was involved in there. Instead, he continued his efforts as a government contractor, working first for Applied Research Associates from 2000 until 2005, then Altus Engineering from 2005 until January 2009, and now SURVICE Engineering.

As a contractor, Bob has been primarily involved in developing input data for helicopter vulnerability analysis models, specifically focusing on subsystems such as the flight controls, hydraulics, rotor controls and blades, armaments, crew, and mission-essential equipment. In addition, he developed an analytical model to expertly estimate Pcd/h values for flight control tubes, drive shafts, and other cylindrical components with a failure mode of severance. He has also been involved in correlating LFT&E test data with pre-test numbers to produce revised Pcd/h data for more than 70 components of the OH-58/ARH. The results from this effort are planned to be documented in an ARL methodology report that promises to further advance the art in aircraft vulnerability analysis.

As with his civilian career, Bob cites many individuals who have been particularly helpful to him during his decade as a contractor. These individuals include Rick Grote, Dirck Ten Broeck, Denise Jordan, Brian Smith, Rob Gangler, Mark Burdeshaw, Tony Steelman, Dyrck Van Dusen, and Bill Keithley. "I especially owe a lot to Bill Keithley," Bob said. "He knows helicopters inside and out, and he's been a very close, terrific coworker."

Today, Bob continues his lifelong fascination with numbers and with trying to make aircraft the most survivable they can be. When asked

about any future goals, he says he would still like to help create a model that can more accurately predict the effects of HE projectiles against aircraft. And he has several words of advice for new or future survivability analysts.

"Speak well and write well," he said. "And document everything of importance. Also, when asked to review someone else's work, don't hold back when it comes to criticism or praise. Speak out and say what you think."

As for his personal life, the 73-year-old spends most of his free time playing golf (trying to turn large numbers into smaller ones), traveling (to Maine every year), walking (usually three to four miles per day), and tutoring math at Harford Community College. He and his wife, Cathy, reside in Havre de Grace, MD. They have three children, six grandchildren, and two great grandchildren.

Congratulations, Bob, on your Excellence in Survivability, and thank you for your half century of service supporting the DoD, the survivability discipline, and the US warfighter. ■

2009 NDIA CSD Aircraft Survivability Awards and Presentations

by Dennis Lindell

The National Defense Industrial Association's (NDIA) Combat Survivability Division (CSD) held its annual Aircraft Survivability Symposium at the Naval Postgraduate School (NPS) on 3–6 November 2009. The Aircraft Survivability 2009 theme was "Next Generation Requirements." As the theme implies, the symposium explored new approaches to integrate and balance aircraft survivability for today's war on terrorism, while remaining prepared for future high-intensity conflicts. The keynote speakers were Lt Gen David A. Deptula, USAF, deputy chief of staff for Intelligence, Surveillance and Reconnaissance, and Mr. Charles (Tom) Burbage, executive vice president and general manager, F-35 Program Integration, Lockheed Martin Corporation.

NDIA CSD Awards

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

The Admiral Robert H. Gormley Leadership Award, named in honor of the CSD's founder and Chairman Emeritus, was presented to Mr. Alan D. Bernard, Massachusetts Institute of Technology, Lincoln Laboratory. The NDIA Combat Survivability Award for Technical Achievement was presented to Mr. Larry F. Pellett, Lockheed Martin Aeronautics. The presentations were made by Mr. Robert Palazzo, CSD Awards Committee Chairman, Dr. Frank Svehlosky, 2009 Symposium Chairman, BG Stephen D. Mundt, USA (Ret), CSD Chairman, and RADM Robert H. Gormley, USN (Ret), CSD Chairman Emeritus.

Admiral Robert H. Gormley Leadership Award

The Admiral Robert H. Gormley Leadership Award is presented annually to a person who has made major leadership contributions to combat survivability. The individual selected must have demonstrated outstanding leadership in enhancing the overall discipline of combat survivability, or played a significant role in a major aspect of survivability design, program

management, research and development, modeling and simulation, test and evaluation, education, or the development of standards. The emphasis of the award is on demonstrated superior leadership over an extended period. The 2009 Admiral Robert H. Gormley Leadership Award was presented to Mr. Alan D. Bernard, MIT Lincoln Laboratory. The citation read—

Mr. Alan Bernard is recognized for exceptional and sustained leadership in the field of aircraft combat survivability. His 46 years of industry and DoD experience span the areas of research, development, test and evaluation, as well as operational assessments. He is nationally recognized for his contributions to the aircraft survivability field, including stealth and electronic warfare. Mr. Bernard has held leadership positions of increasing scope and importance at Lincoln Laboratory. He was the Leader of the Systems Analysis Group supporting the Air Force Secretary of the Air Force/Acquisitions Special Programs (SAF/AQL) "Red Team" activities, evaluating stealth, electronic countermeasures, weapons technologies, capabilities, and vulnerabilities. He was a pioneer in using systems analysis to understand the interactions of survivability and technology which helped define the iconic Red vs. Blue "Kill Chain" framework. In addition, Mr. Bernard has been involved in almost every USAF aircraft and weapons program in the last 30 years, such as the F-117, B-2,

F-22, F-35, Dark Star, Predator, Global Hawk, Advanced Cruise Missile, Joint Air-to-Surface Standoff Missile, and numerous other unacknowledged programs. Presently, the Associate Division Head of Lincoln Laboratory's Tactical Technology Division, Mr. Bernard is responsible for the technical operation of the technical staff, who provide research and analysis for the US Military to include "Red Team" analyses in support of the Air Force's Rapid Capabilities Office on their efforts in a wide variety of classified technology and mission areas.

The 2009 Admiral Robert H. Gormley Leadership Award acknowledges the exceptional and visionary contributions of Mr. Alan D. Bernard to aircraft combat survivability, the Armed Forces, and the nation.

Admiral Robert H. Gormley Leadership Award: From left to right—Dr. Frank Svehlosky, 2009 Symposium Chairman; BG Stephen D. Mundt, USA (Ret), CSD Chairman; Mr. Alan D. Bernard, MIT



2009 RHG Leadership

Lincoln Laboratory, Admiral Robert H. Gormley Leadership Award recipient; and RADM Robert H. Gormley, USN (Ret), CSD Chairman Emeritus.

Combat Survivability Award for Technical Achievement

The NDIA Combat Survivability Award for Technical Achievement is presented annually to a person or team who has made a significant technical contribution to any aspect of survivability. It may be presented for a specific achievement or for exceptional technical performance over a prolonged period. Individuals at any level of experience are eligible for this award. The 2009 Technical Achievement Award was presented to Mr. Larry F. Pellett, Lockheed Martin Corporation. The citation read—

Mr. Larry Pellett is recognized for exceptional technical achievement in the field of aircraft combat survivability. Over the past 25 years, he has made significant contributions in the development of highly survivable weapon system designs, sensor integration, and system testing. He pioneered efforts in radar cross-section testing and the development of a unique indoor RCS test capability, the first of its kind in the country. Mr. Pellett became the key driver in the development of a new compact range test facility at Rye Canyon and directed improvement to the world's premier outdoor range facility at Helendale, CA. He has held many key positions at Lockheed Martin Aeronautics, to include Chief of the Electro-Magnetics Division where he led technology development on advanced radomes, antennas, ranges and measurement systems, and special materials. Mr. Pellett was the Skunk Works lead on the F-22 program focused on the Management and Survivability Organization managing over 350 engineers and scientists at three sites across the country. Mr. Pellett has demonstrated exemplary technical skills in the field of aircraft survivability, having been instrumental to the success of the F-22, F-35, F-117, and many other Advanced Development Programs.

This award for Technical Achievement acknowledges the exceptional and visionary contributions of Mr. Larry Pellett to aircraft combat survivability, the Armed Forces, and the nation.

Combat Survivability Award for Technical Achievement: From left to right—Dr. Frank Svehosky, 2009 Symposium Chairman; BG Stephen D. Mundt, USA (Ret), CSD Chairman; Mr. Larry F. Pellett, Technical Achievement Award recipient; and RADM Robert H. Gormley, USN (Ret), CSD Chairman Emeritus.



2009 Tech Achievement

Warfighter Presentation to Dr. Robert E. Ball

At the end of his welcome and opening remarks to the symposium, VADM Daniel T. Oliver, USN (Ret), President of the Naval Postgraduate School, called NPS Alumnus LCDR Stephen D. Nordel, USNR; BG Stephen D. Mundt, USA (Ret), CSD Chairman; CDR Christopher Adams, USN (Ret), Director of the NPS Center for Survivability and Lethality; and NPS Distinguished Professor Emeritus, Dr. Robert E. Ball to the stage for a presentation. As many know, Professor Ball is a living legend in the aircraft survivability community. He originated the Aircraft Combat Survivability education program at NPS in the late 70s, wrote the 1985 and 2003 American Institute of Aeronautics and Astronautics textbooks on the fundamentals of aircraft combat survivability analysis and design, and taught some 4,000 military, civilian, and industry students over two decades.

President Oliver, General Mundt, CDR Adams, and LCDR Nordel, a thesis student of Professor Ball, presented Professor Ball with an American flag that had been flown over Iraq by LCDR Nordel on behalf of military aviators around the world, the aircraft survivability community, and the NPS Center for Survivability and Lethality for his lifetime of work and achievement in enhancing the Aircraft Combat Survivability discipline. The citation read—

On January 15, 2008, Marine Tactical Electronic Warfare Squadron 4 deployed to Marine Corps Air Station Al Asad, Iraq, in support of Operation Iraqi Freedom. The dedication and steadfastness of the "Seahawks" in their continuing support of the Global War on Terror is playing a crucial role in the establishment of a free and democratic Iraq. On April 25, 2008, this American flag was flown into combat in an EA-6B Prowler during Operation Iraqi Freedom 06-08 for Dr. Robert E. Ball for your lifetime commitment to the protection of our lives and aircraft. The mission originated from Marine Corps Air Station Al Asad and was conducted in Iraqi airspace for the duration of the flight. During the 5.3-hour mission, Sancho 32 provided electronic warfare protection and support for coalition ground units engaged by insurgents trying to destabilize the newly formed Iraqi government.

Dr. Ball with citation and the American flag flown over Iraq.



Dr. Ball

Best Poster Papers

Awards were also presented for the symposium's top three poster papers. First place went to Mr. David Sparks of Bell Helicopter for his paper, "Understanding Asymmetric Acoustic & Visual Threats to Rotorcraft." Second place went to Mr. Pat Buckley of SURVICE Engineering for his paper, "Shortline Processing on Multi-Core Processors." Third place went to Mr. Ed Pevler of Southwest Research Institute for his paper, "Analysis of RF

Simple Automatic Fire Suppression

by Joe Manchor

In-flight fire can be disastrous, especially if occurring in a large open space, such as the main cabin area of a rotorcraft. To combat fire, most aircraft are equipped with hand-held extinguishers. But fires may occur in inaccessible areas that may not be reached with the hand-held extinguisher. Additionally, flammable fluid fires, such as those that may occur after enemy encounters, can be particularly difficult to extinguish. For such fires, it is often important to extinguish as quickly as possible to prevent the spread of burning fuel to the point that the fire becomes unmanageable.

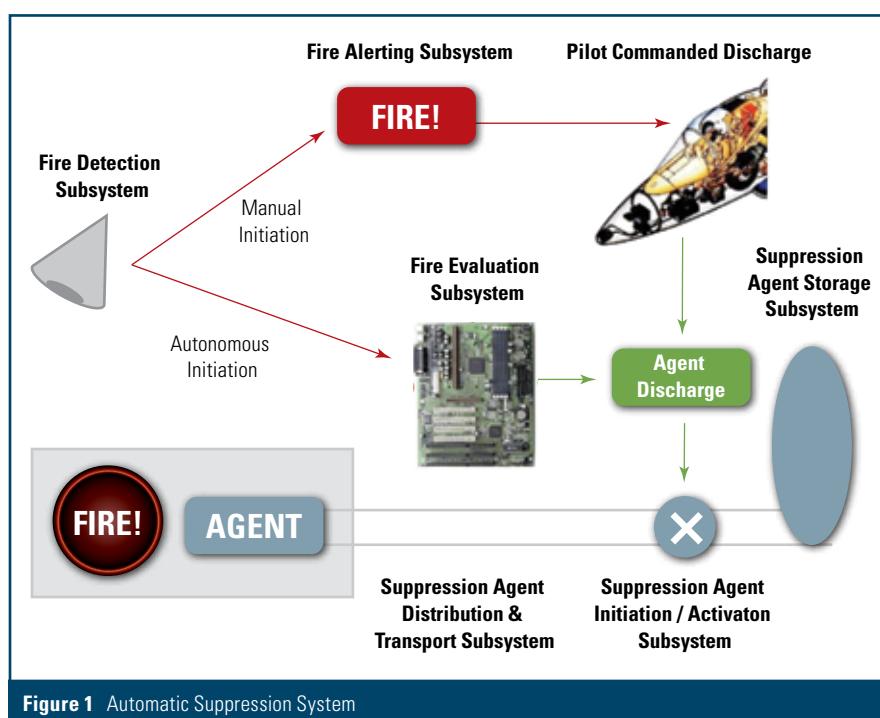


Figure 1 Automatic Suppression System

Protecting against ballistically induced fire is preferably achieved via passive means. Fuel containment technologies, such as self-healing fuel bladders or fuel line suction feed systems, are usually the first line of defense. Should passive technologies prove inadequate, it may sometimes become necessary to consider fire suppression systems.

An automatic system would be desired because it could quickly react to improve the chances of extinguishing the fire. Automatic systems can be costly and complex, with numerous subsystems. As seen in Figure 1, an automatic system can include fire

detection, evaluation, alerting, and activation, along with suppression agent storage and distribution subsystems. Some of these subsystems may require interface with aircraft systems, such as the electrical system, further aggravating the complexity of the suppression system.

As system complexity increases, so does the potential for false alarms and/or failure. The system can also become unacceptably costly and heavy. As a result, some aircraft programs have been forced to forego needed fire

protection, and accept some of the vulnerabilities imposed by their flammable fluid systems.

In 2003, the Joint Aircraft Survivability Program (JASP) sponsored a small project that evaluated the potential for simplification of aircraft fire suppression systems. The objectives of the Simple Passive Extinguisher (SPEX), JASP Project V-3-02, were to minimize the cost and weight impact of automatic fire suppression systems, while enhancing retrofit potential, allowing for possible kit installation on the battlefield, if needed.

The SPEX concept focuses on simplifying or eliminating as much as possible of the subsystems normally associated with active suppression systems. The characteristics of a fire alone, such as heat, would serve as the mechanism to initiate automatic activation of the system. An extremely simplified example of the SPEX concept may be thought of as a balloon filled with a fire suppression agent. Such a balloon would be placed in a fire vulnerable area. Heat from a fire would burst the balloon, releasing the agent to extinguish the fire.

While the above example is overly simplified, under this project several "Contractor Off-The-Shelf" (COTS) automatic suppression systems were identified that actually emulated this concept. These systems were mature enough to have potential for military

Continued on page 31

Joint Cargo Aircraft Hydrodynamic Ram LFT&E

by Scott Wacker, Marcus Miller, and Dan Cyphers

The Joint Cargo Aircraft (JCA) Program is a joint US Army/US Air Force program formed to procure, field, and sustain a multifunctional fixed wing cargo aircraft. The JCA's primary mission is to provide direct support airlift of time-sensitive, mission-critical cargo to Army forces operating in remote, austere areas. The current concept of employment envisions the JCA flown by Air National Guard units under the tactical control of Army Combat Aviation Brigades or Aviation Task Forces. As a new military weapon system acquisition, the JCA was subject to the live fire test and evaluation (LFT&E) law. The JCA LFT&E strategy included live fire testing of selected components, subassemblies, and subsystems as well as design analyses, modeling and simulation, and analysis of combat data. The JCA LFT&E hardware testing was grouped into six major test categories.

- Group 1—Crew Armor, Emergency Supplemental Oxygen Supply, Energetics
- Group 2—Flight Controls, Hydraulics
- Group 3—Fire Detection/Suppression System, Engine, Propeller
- Group 4—Wing Iron Bird
- Group 5a—Dry Bay Fire Suppression, Ullage Explosion
- Group 5b—Hydrodynamic Ram, Wing Structure

The JCA LFT&E Group 5b test series was established to evaluate the reduction/loss of flight load carrying capability of the JCA wing due to hydrodynamic ram (HRAM) and structure removal/damage. Combat representative ballistic threats were fired at nominal impact velocities into a production C-27A wing, which was representative of a JCA wing in the areas relevant to this program. The test article was filled with water (to simulate JP-8 fuel) and structurally loaded to simulate aerodynamic flight loads. Damage resulting from the ballistic impact and resulting hydrodynamic ram, along with instrumentation data gathered during testing and post-test reloading, is being evaluated and quantified for input into a nonlinear LS-DYNA Finite Element Analysis (FEA) evaluation. The analysis will evaluate any loss of aircraft structural load-carrying capability. All resulting test and analysis data will then be used to refine vulnerability estimates of the JCA for wing hydrodynamic ram,

providing the Army and Air Force with a reasonable assessment of the vulnerability of the JCA aircraft wing to combat representative threats.

This test series was a joint effort between the 46th Test Wing, 780th Test Squadron's Aerospace Survivability and Safety Operating Location (780 TS/OL-AC) at Wright-Patterson Air Force Base (WPAFB), OH, and the Naval Air Warfare Center/Weapons Division (NAWC/WD) at the Weapons Survivability Laboratory (WSL) in China Lake, CA. The 780 TS/OL-AC was responsible for overseeing all hydrodynamic ram test activities, including test planning, provisioning, conduct, analysis, and reporting. Testing was performed by the NAWC/WD at the WSL.

All testing was performed for a single load case involving a 1g straight and level (up-bending) cruise condition. Extrapolations were necessary for other portions of the JCA flight regime to provide data for required vulnerability analyses. To assist with these extrapolations, RHAMM Technologies LLC and L-3 Communications are evaluating the damage on safety margins during 1g flight, and L-3 will also perform an assessment for a 2.1g banking scenario, a 2.1g symmetric pull-up scenario, a gust condition, and a landing scenario (down-bending case).

Alenia also supported the analysis with load data and knowledge of the wing's design limit load capability.

Test Article Description

For this LFT&E program, C-27A wings were used as production representative test articles. C-27A wings are structurally representative of JCA wings, particularly in the outer wing. Some structural differences between the JCA and C-27A do exist in the center wing structure due to requirements for increased maximum takeoff weight (MTOW) and increased birdstrike requirements. The center wing differences were not factors in this program because the center wing is typically not filled during a combat mission, so it was not tested.

JCA Wing Structure

The JCA wing is divided into three major sections: left- and right-hand outer wing sections, and a center wing section. The outer wings contain the main fuel tanks, each with a capacity of 888 gallons of fuel, and the center wing section contains two auxiliary fuel tanks, each with a capacity of 740 gallons of fuel (Figure 1). The center wing is connected to the fuselage through six fixed points and six link-type points. In addition, a dry bay separates the auxiliary fuel tanks and is located directly above the fuselage.

The center wing section is composed of three spars, composite ribs, and a chem-milled upper skin. The lower wing

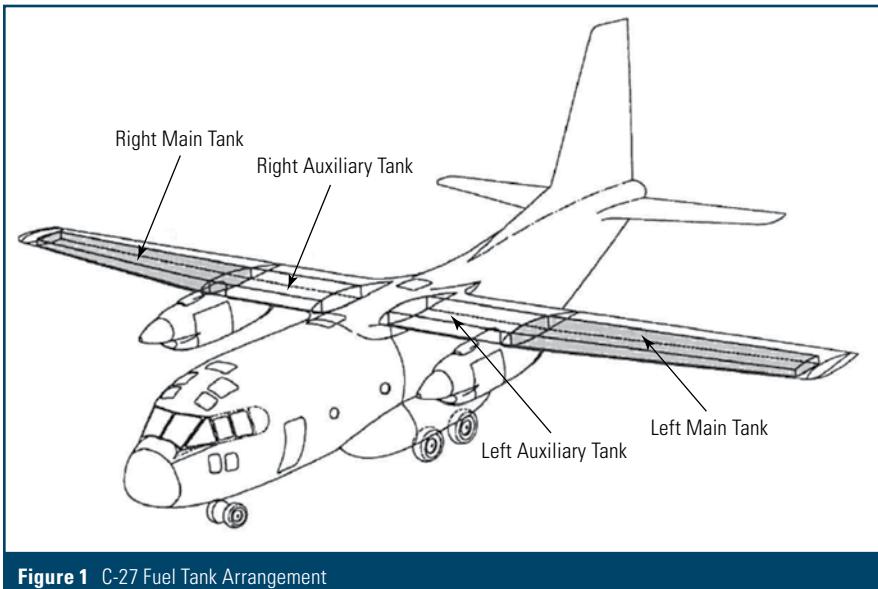


Figure 1 C-27 Fuel Tank Arrangement

skin is of variable thickness, and both the upper and lower skins are stiffened with Z-shaped stringers. The structure of the outer wings is similar to the center wing section with chem-milled, variable thickness upper and lower skins.

The fuel tanks are integral parts of the center and outer wing. The outer mold line (OML) of the fuel tanks are formed by the upper and lower wing skins and the front and rear spars, with a bulkhead separating the center wing tanks from the outer wing tanks. Each main tank is divided longitudinally into two interconnecting parts by a center spar, and transversely by five partitions.

Fuel System Description

Fuel is stored in the four previously mentioned integral tanks, having a maximum total capacity of 3,256 gallons (21,458 lbs). Under normal operation, the left main and auxiliary tanks feed the left turboprop and auxiliary power unit (APU), and the right main and auxiliary tanks feed the right turboprop. However, the JCA has the capability to feed either engine from any of the four fuel tanks during flight through a cross-feed system.

During a normal mission, the auxiliary tanks will be empty at takeoff and remain empty for the duration of the mission. However, the auxiliary tanks are filled during some flight scenarios, particularly during a ferry flight into or out of the operational zone. If damage occurs to the outer wing, a shut-off valve for the appropriate fuel tank will be closed and the cross-feed valve opened, allowing both engines to be fed from the same fuel tank. While on the ground, fuel can be

transferred from any one fuel tank to any other fuel tank. This capability, however, is not available during flight.

For this test series, the wing test articles were filled to the desired levels with water to simulate JP-8 fuel. Water has higher density and bulk modulus values than JP-8 fuel. Therefore, testing with water was considered conservative or worst-case from a survivability standpoint. In addition, the hazards involved with the use of fuel could have overshadowed hydrodynamic ram results or led to destruction of the test article by fire/explosion.

The fuel tanks were pressurized using nitrogen to approximately 1.0 psig to simulate normal operating conditions for JCA fuel tanks. This pressure simulates the net effect from the

Onboard Inert Gas Generating System (OBIGGS). To appropriately assess the potential net damage effects of hydrodynamic ram, it was necessary to simulate the actual baseline pressure.

Test Setup

The C-27A wings were prepared and instrumented to ensure the primary test objective was met. The wings were mounted to a load fixture, which was designed and fabricated by 780 TS/OL-AC Aerospace Vehicle Survivability Facility (AVSF) personnel at WPAFB. AVSF personnel also designed a hydraulic load system that was used to load the wing. The load fixture, hydraulic load system, and wing were then shipped to the WSL in China Lake, CA, where they were installed at the Live Fire Test Site, the newest and most modern test facility at the WSL (Figure 2).

Test Fixture Design

The test was designed to utilize both the center and outboard portions of the wing, which required that the center wing section of the test article be supported at the test fixture in the same manner as it would on the aircraft fuselage. This was accomplished using a heavy steel reaction base test fixture consisting of a wide platform made of steel I-beams (which were securely bolted to the test site pad) and a heavy-duty, steel-box-like structure for mounting the center wing (Figure 3). The center wing was attached to the fixture by utilizing the 12 center wing-to-fuselage mounting points in the same manner it attaches to the actual aircraft fuselage. The left-hand outboard wing was then mounted to the center wing using production attachment bolts. The



Figure 2 C-27 Test Article Installed on the LFT Site at the WSL



Figure 3 Image of Center Wing Attached to the Load Fixture and Steel I-Beams

test fixture was secured to the test pad using eight heavy-duty steel boxes (total weight approximately 105,164 lbs) that were positioned on the steel I-beams and used as ballast weight to counteract the moment induced while loading the wing.

Wing Loading

The wing loading in this program was applied in an effort to simulate flight loads sustained by the wing during the cruise condition of a low-altitude air drop. Bending moment and shear loads applied during each test matched as closely as possible with values provided by L-3/Alenia. Load/deflection curves were used to verify the predicted load levels. A 10-cylinder hydraulic load system was used to apply structural loads to the wing during each hydrodynamic ram test. Eight of the load cylinders applied the load at three different load stations along the left-hand outboard wing, and two cylinders were used to react the load at the right-hand outboard-to-center wing interface.

This system was a closed-loop, force feedback hydraulic system, which was comprised of a 3,000 psi hydraulic power unit, a servo controlled valve manifold, and two proportional-integral-derivative (PID) digital motion controllers. The system was connected to a personal computer (PC) via ethernet and was controlled using a LabView user interface operated on the PC that allowed the operator to control the system remotely over a fiber link. The loads were monitored using compression load cells in conjunction with current loop isolators and motion controllers to regulate the load provided by the hydraulic cylinders. The load cells provided force feedback to the PID motion controller, which allowed the cylinders to be controlled in a closed-loop during the test.

During the loading process, each of the cylinders was operated independently in an open-loop, allowing for manual positioning of the load pad on the wing as the operator extended/retracted the cylinder. After all the load pads were positioned properly against the wing, the cylinders were switched to closed-loop control with the motion controller maintaining the desired preload for all cylinders. The master control was then used to slowly advance all the hydraulic cylinders simultaneously until they reached the desired percentage of their programmed maximum load. For each test, a unique load condition was applied with a desired maximum load programmed for each hydraulic cylinder. The motion controller allowed proportional, coordinated control of each load cylinder up to the maximum (100%) for each test.

Each load cylinder applied its load to the wing by pushing up against the bottom surface of the wing with a gimbaled, conformal pad, distributing the load in a manner that avoided damaging the wing at the load application point. The conformal pad consisted of an 18-inch square steel plate topped by a

combination of 20 psi Styrofoam, plywood, and neoprene rubber to act as an intermediary load transferring mechanism. The plywood, neoprene, and Styrofoam interfaced with the wing skin and spars through load pads, covering a much wider area than the hydraulic cylinder itself. The maximum allowable loads provided by L-3/Alenia were monitored and controlled to ensure the skin was not overloaded during testing.

Load station locations along the wing were selected based on predetermined factors of safety for localized spar and rib buckling. Figures 4 and 5 illustrate the locations of the outboard and inboard load stations. The inboard shear load required for the test was calculated first, and then the remaining outboard shear loads were calculated to achieve the appropriate impact location bending moment loads. During the loading process, the applied loads and deflections along the wing were monitored and compared to values provided by L-3/Alenia and calculated by RHAMM using their LS-DYNA model developed for this program.

Prior to each test, the dry wing (i.e., the wing without any water) was loaded to the desired maximum load to assess the validity of the repair and to provide baseline data for the subsequent test. In preparation for the ballistic test, the wet wing was loaded to the desired maximum test load and maintained in closed-loop control until the test event occurred. As the test event transpired, the LabView interface monitored the wing for excessive loads and deflections. Following a post-test inspection, the damaged dry wing was re-loaded to the pretest dry load level. Once re-loaded, stress/strain and deflection levels were evaluated for any changes in wing characteristics.



Figure 4 Outboard Load Station Locations



Figure 5 Reaction Load Station Location

Instrumentation

Instrumentation for this testing was required to determine threat impact velocity (a threat detection system); deflection of the wing skin and structure during loading and threat impact (deflection potentiometers); magnitude of load applied to the wing (load cells); magnitude of the hydrodynamic ram pressures created during impact (carbon stress gauges and piezoelectric pressure transducers as a backup); a measure of the axial deformation of the upper skin, lower skin, and spars (strain gages); fluid temperature (thermocouples); fluid leakage rates (a flow metering system);

and the G-force shock/impulse imparted on the wing during impact (single axis accelerometers). Standard-speed and high-speed videos were also used to capture hydrodynamic ram effects (e.g., shock wave propagation through the skin and spar materials, skin/spar web bulging, skin-to-spar joint separation, crack propagation, and fuel spurting) that occurred during the impact event.

Predictions and Analysis

Developing pretest predictions for hydrodynamic ram test programs is both challenging and complex. Many factors influence the amount of damage resulting

from the hydrodynamic ram phenomenon. For this reason, pretest predictions were developed for this test program using physics-based computer modeling. The pretest predictions were completed by RHAMM using an LS-DYNA model of the JCA wing. The results included estimates of potential structural damage such as hole sizes, cracking, and component failure. LS-DYNA is an advanced general-purpose finite element analysis simulation software package that can be used for analysis of complex 3-dimensional models using explicit time integration. LS-DYNA can be used for analyses such as fluid and thermal analysis, crack propagation, non-linear and rigid body dynamics, and smoothed particle hydrodynamics. These predictions draw upon an understanding of essential factors that influence the pressures generated by ballistic threat-induced hydrodynamic ram and the resulting damage. Figures 6 and 7 illustrate an example of RHAMM's pretest prediction capabilities using LS-DYNA.

Following testing, a post-test residual strength analysis was performed. This analysis was performed independently by RHAMM and L-3. For each test, the detailed damage description, including digital images, sketches, and measurements, and the stress, strain, load, and deflection data was provided to RHAMM and L-3. RHAMM incorporated the given damage for each test into their LS-DYNA model and L-3 incorporated the damage into their suite of models to determine how the loads redistribute, how the stresses and displacements change, if the damage progresses, and then determined if there is a loss of load-carrying capability. RHAMM performed an analysis of all six tests for the 1g load case and L-3 performed an analysis for all tests for the 1g load case and the other excursion load cases mentioned earlier. If the wing survived, margins of safety were examined for the maximum stress areas to determine how much more load the wing can endure. The results of the residual strength analysis will be used to produce inputs for vulnerability assessment efforts, which will quantify JCA wing vulnerability to ballistic threat-induced hydrodynamic ram and structure removal/damage.

Test Results

A total of six ballistic tests using three different threats were completed during this test program. Analysis of the test

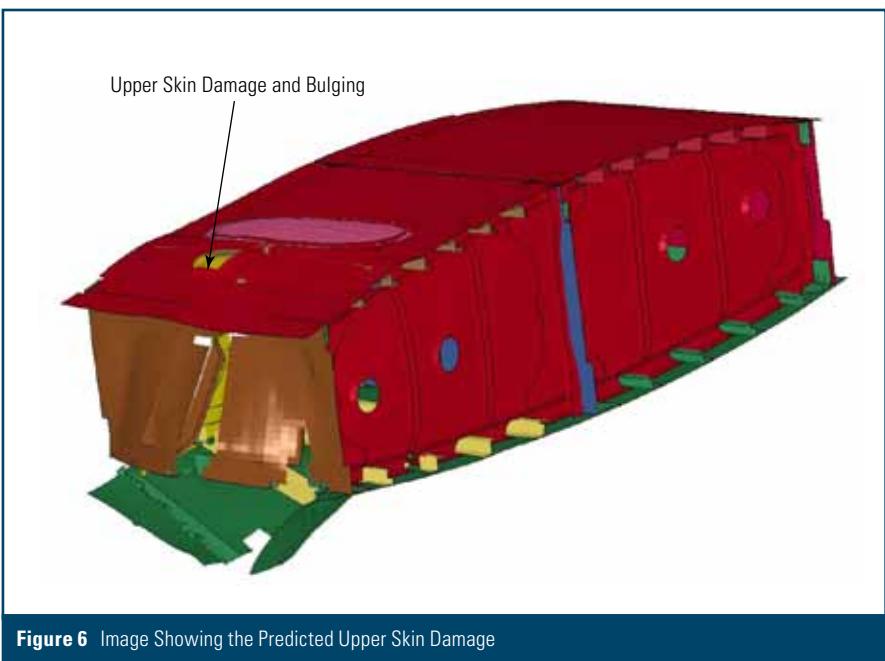


Figure 6 Image Showing the Predicted Upper Skin Damage

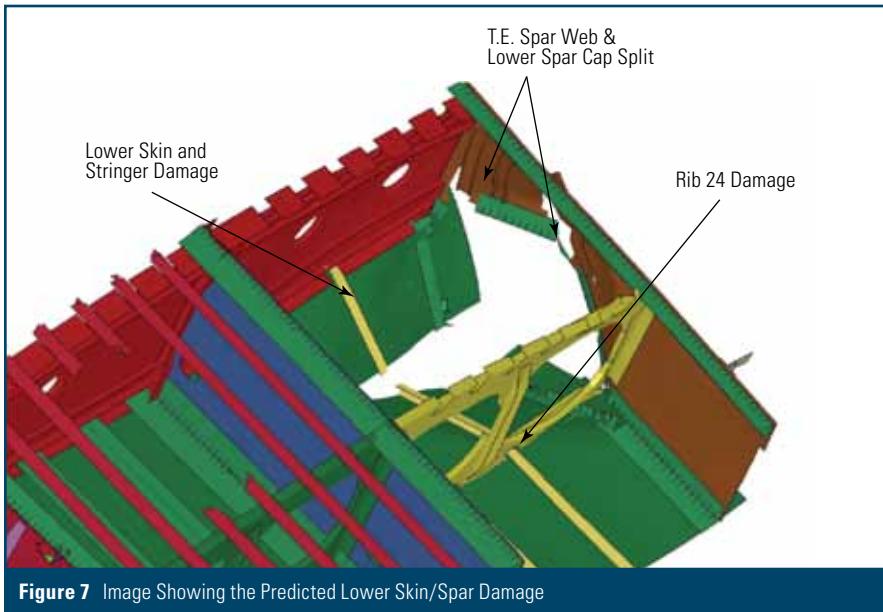


Figure 7 Image Showing the Predicted Lower Skin/Spar Damage

data and analytical extrapolations for other portions of the JCA flight regime are currently underway. The final report for this program will be released in 2010.

The successful completion of this test program is a credit to the many cooperating organizations, including the Army, Air Force, Navy, and their contractors, who were able to work together to complete the first major fixed wing LFT&E test program affected by Base Realignment and Closure (BRAC) 2005. The compressed nature of the JCA LFT&E program forced this complex test series to occur in a relatively short period of time. With the Army managing the LFT&E program, the Air Force providing oversight and test planning and preparation for this test series, and

the Navy conducting the testing, all elements were successful in coming together to complete the test objectives. The results will ensure an understanding of the effects of hydrodynamic ram on the JCA and provide useful data to future LFT&E programs. ■

2009 NDIA CSD Aircraft Survivability Awards and Presentations *Continued from page 22*

Terrorism Theory Compared to Unusual Aviation Incidents—Have We Been Attacked?"

Best Poster Paper Awards:
From left to right—Dr. Frank Svehlosky, 2009 Symposium Chairman, Mr. Michael Schuck for Mr. Pat Buckley, Mr. Ed Pevler, Mr. David Sparks, and Mr. Ron Dexter, Displays and Poster Paper Chairman.



2009 Poster Papers

successes in enhancing combat aircraft survivability and explore applying the lessons learned to future requirements and challenges. Details regarding the 2010 Symposium Call for Abstracts, Displays, and Award Nominations will be available on the event Web site, <http://www.ndia.org/meetings/1940>.

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

Aircraft Survivability 2010

Preparations are underway for Aircraft Survivability 2010, "Today's Successes, Tomorrow's Challenges." Scheduled for 2–5 November 2010, this important event will highlight government, industry, academia, and military

Joint Cargo Aircraft LFT&E Program

by Steven Duda

The Joint Cargo Aircraft or JCA (C-27J) is an intra-theater fixed wing cargo aircraft intended to deliver time-sensitive cargo to the last tactical mile. The program started as an Army program to replace and consolidate the Army's fixed wing cargo fleet of C-23 and certain C-12 aircraft. The program was later directed to merge with the Air Force (AF) Light Cargo Aircraft (LCA), which would augment C-130 intra-theater capabilities. The LCA would improve airlift efficiencies by eliminating the need to fly mostly empty C-130 aircraft to deliver small, time-sensitive loads.



As a newly fielded cargo aircraft designed to deliver cargo to the most forward based troops, the JCA is expected to be survivable within its intended operational environment. Features contributing to JCA survivability include ullage inerting, rugged/robust aircraft structures, many redundant critical components, flight crew ballistic armor protection, and a suite of integrated Aircraft Survivability Equipment (ASE).

The JCA met the criteria for requiring live fire test and evaluation (LFT&E) in accordance with Title 10 US Code, Section 2366; commonly referred to as the "Live Fire Test Law." The system obtained a waiver from Full Up System Level (FUSL) LFT&E on the grounds that it would be prohibitively expensive and unpractical. The program developed a strategy to evaluate aircraft survivability utilizing component and subsystem ballistic testing along with modeling and simulation (M&S) to obtain a system-level survivability assessment, as documented in the Alternate Live Fire Plan.

The JCA LF Integrated Product Team (IPT) is a diverse group that encompasses the necessary skill sets to support the comprehensive LFT&E program. The LF IPT is chaired by US Army Evaluation

Center as the lead operational test agency (OTA) responsible for identifying critical issues and evaluation criteria, and authoring the LFT&E evaluation reports to inform the milestone decision authority. The Army Research Laboratory Survivability Lethality Analysis Directorate (ARL SLAD) at Aberdeen Proving Ground, MD, serves as the Army lead agency for execution of LFT and analysis efforts. The 780th Test Squadron (780th TS/OL-AC) at Wright-Patterson Air Force Base (WPAFB) is the AF agency responsible for planning and reporting on live fire testing; the 780th TS/OL-AC has supported this LFT&E program with ARL SLAD. Similarly, the Aeronautical System Center Engineering Directorate, Combat Effectiveness and Vulnerability Branch (ASC/ENDA) at WPAFB is the AF agency responsible for analysis of survivability; ASC/ENDA supported vulnerability analysis with ARL SLAD. The Naval Air Weapons Center (NAWC) executed those test groups conducted at NAWC test ranges in China Lake, CA. User representatives from the Army and AF both support the LF IPT, providing a Soldier/Airman perspective that is vital for assessing survivability in an operational context. The Joint Program Office (JPO) is responsible for planning and managing resources associated with the acquisition, including LFT&E; the JPO also provides additional system engineering and operational knowledge. The prime and subcontractors also support the LF IPT, as needed, to provide technical data and engineering support to support planning and analysis. The Office of the Assistant Deputy Under Secretary of the Army for Test and Evaluation (DUSA-TE) provides lead service oversight, ensuring that all Department of Defense (DoD) and Army

regulations are appropriately followed. The Director, Operational Test and Evaluation for Live Fire Test and Evaluation (DOT&E LFT&E) provides DoD-level oversight and authors the Beyond Low Rate Initial Production (BLRIP) report for Congress.

The critical issues identified in the Alternate Live Fire Plan were to be assessed in a series of ballistic test groups, with the results being pulled together via M&S to obtain a system-level assessment. Due to the aggressive acquisition schedule of the JCA, the LF IPT chose to utilize each of the services (Army, AF, and Navy) LFT&E test ranges to support the overall ballistic test program. The LFT&E ballistic test groups for JCA are Armor (planned, conducted, and reported by ARL SLAD); Oxygen System (planned, conducted, and reported by ARL SLAD); Flight Controls (planned, conducted, and reported by ARL); Dynamic Propeller (planned and reported by ARL SLAD, conducted by NAWC); Engine Nacelle Fire Detection and Suppression (planned, conducted, and reported by 780th TS/OL-AC); Wing Dry Bay Fire via Wing Iron Bird Simulant (planned, conducted, and reported by 780th TS/OL-AC); Wing Dry Bay Fire via Production Representative Wing (planned and reported by 780th TS/OL-AC, conducted by NAWC); Wing Hydrodynamic Ram (planned and reported by 780th TS/OL-AC, conducted by NAWC), and Man Portable Air Defense System (planned and reported by 780th TS/OL-AC, conducted by NAWC). Additionally, ARL SLAD conducted a white paper assessment of ALE-47 flare dispensers' (and associated infrared countermeasure expendables or flares) impact on system and crew and passenger vulnerability.

Lastly, ARL SLAD leads the M&S vulnerability analysis effort with close coordination and support from ASC/ENDA. As of November 2009, the engine nacelle fire detection and suppression test group is underway and all other test groups have been successfully executed.

One major effort early in the program was to locate applicable existing ballistic test and analysis data. The program was largely successful in this effort. Considerable test and analysis data from prior C-130 LFT&E were useful in assessing JCA (propeller, engine, flight controls, structure, and fire vulnerability), as well as V-22 engine data. Even when vulnerability data from prior LF programs were not directly applicable, the test methodologies documented in past test plans for similar test events still proved valuable. This is a testament to the value of data bases like those maintained by the Survivability Vulnerability Information Analysis Center (SURVIAC) and Defense Technical Information Center (DTIC).

A second major effort was to locate/secure suitable ballistic test hardware. A retired C-27A at Davis-Monthan AFB proved to be a tremendously valuable source of ballistic test hardware. The C-27A proved largely representative of the C-27J in terms of structure and components other than propulsion, which had been entirely changed between the A and J models. Even when new JCA (C-27J) hardware was required, the C-27A often served as a test fixture that reduced test setup time and improved overall fidelity of test data. The JCA LF IPT is greatly appreciative to the US Department of State for releasing C-27A hardware in support of the JCA Program. The C-27A hardware greatly reduced cost and schedule associated with many of the LF test groups. Additionally the 46th Test Wing at WPAFB had developed a hot engine core simulant to support the C-130 LFT&E; this hardware along with lessons learned that improved the surrogate's fidelity were combined with a production JCA engine nacelle and fire suppression system to support the Engine Nacelle Fire Detection and Suppression Test Group. The hot core simulant greatly reduced the cost of test as an operating engine would have otherwise been required. Similarly, the group at China Lake NAWC possessed an appropriate surrogate power plant and gear box to support the Dynamic Propeller Test Group. The methodology and test

hardware required to precisely impact a rotating propeller blade had been developed and refined over the years, by both ARL SLAD and NAWC, to impact dynamic helicopter rotor blades as part of prior LFT&E programs. The JCA LFT&E program marks the first LFT&E ballistic test against dynamic propeller blades.

Development of the crew, passenger, and system-level vulnerability analysis has remained a major effort throughout the LFT&E program. This involves multiple tasks, including building a target description, building threat data files (if they do not already exist from other LF efforts), identifying and defining flight profiles/vignettes, developing initial vulnerability inputs, refining vulnerability inputs based on test data, conducting final vulnerability analysis, and writing verification and validation (V&V) reports. The target description work is one of the first activities to get underway because it is so time consuming. The final vulnerability analysis and the V&V report are the very last activities to be completed prior to the preparation of the LFT&E evaluation report because it must reflect all the lessons learned throughout the LFT&E test program.

One aspect of the vulnerability analysis effort that contributed most significantly to staying on track to meet the aggressive JCA schedule was the expedient development of a wholly government-owned target description. ARL SLAD, with support for JPO, ASC/ENDA, and government contractors, utilized metrology equipment and hand measurements to develop the target description. Initial measurements were made on the C-27A at Davis-Monthan AFB and later updated with measurements of JCA-1 and JCA-2 at the prime contractor's facilities in Waco, TX. This approach had several advantages beyond its expediency. The advantages stem largely from the fact that the level of detail of the target description is based on what is required to support a vulnerability analysis. The level of detail is important because if an aircraft manufacturer's "build from" computer-aided design (CAD) files were used, the level of detail would be too great and would in essence crash the vulnerability analysis model—or the "build from" CAD files would need to be "dumbed down," which is a very time-consuming process. In addition, because the target description was developed purely from government resources and is not of a "build from" level of detail, the additional

distribution restrictions associated with vendor proprietary data are not as strict, making the flow of data easier within the government. Since the target description is government-owned, it can easily be used for future analysis to include survivability design trade studies.

The JCA LFT&E program is unique because of the extent that it taps into the experience and expertise of the tri-service aircraft survivability community. This approach was largely driven by schedule, but also in part because of the joint Army and AF designation. The entire LFT&E program from beginning to end had to be executed between Mile Stone C (MS C) and Full Rate Production (FRP), with aircraft source selection occurring at MS C. No one service could have provided the manpower and test range capabilities to support this program within its schedule without sever impact to other test programs. All members of the LF IPT have been impressed with the accomplishments achieved to date. Having such a large group involved in an LFT&E program could easily become problematic. Capitalizing on each member's strengths and maintaining an understanding that all products support one customer and one final product helped maintain focus and keep each individual effort in perspective.

Just as the JCA LFT&E program was able to leverage the lessons learned from prior LFT&E, it is expected that other programs (both upgrades and new builds) will benefit from the lessons learned and new test methodologies utilized during JCA LFT&E. These lessons will help fulfill further improvements in the arena of aircraft survivability. In this way, LFT&E is an investment in future programs both contributing to increased survivability and reducing the cost and effort to evaluate future programs. ■

Simple Automatic Fire Suppression Continued from page 23

aircraft applications. They were subsequently demonstrated in full-scale aircraft testing to evaluate their potential to automatically detect and extinguish ballistically induced fuel fire. The results of these tests were very encouraging, with one system in particular showing promise.

The Firetrace Aerospace automatic suppression system was shown effective in automatically detecting, activating, and extinguishing fires within a reasonable time. It should be noted that this system requires no electrical power or interface with any of the aircraft systems. For testing, it was merely mounted within the void space that it was to protect, highlighting its potential for retrofit and rapid fielding. Figure 2 shows the results of one of these tests.

As a result of the JASP SPEX project tests, both the P-8A Poseidon and V-22 Osprey programs conducted trade studies to evaluate the Firetrace system for their aircraft. Both programs found that it did meet their needs for ballistic fire suppression. As such, both aircraft have selected this technology to be included as part of their ballistic vulnerability reduction design.

The Firetrace system has also been evaluated for several other rotorcraft platforms and various applications under JASP and Joint Live Fire (JLF)



Figure 3 JLF Firetrace Testing for Rotorcraft Main Cabin Fire Protection

sponsorship. These tests have varied from providing fire protection for small inaccessible aircraft voids, to suppressing large conflagrations in rotorcraft main cabin areas. Figure 3 shows a main cabin test, and illustrates that the system is very capable of detecting and extinguishing large fires in open, well-ventilated areas.

In August 2009, JASP provided recommendations for rotorcraft survivability improvement technologies for potential Director of Defense Research and Engineering sponsorship under the Secretary of Defense' Task Force on Helicopter Survivability. These technologies were required to be mature enough for rapid fielding. The Firetrace system was proposed as one of several vulnerability reduction

technologies that would provide significant improvement to rotorcraft survivability.

Since the 2003 SPEX testing, automatic suppression systems have been developed and marketed by other vendors that also emulate the SPEX concept of minimized subsystems. Similarly, some of these do not require interface with aircraft systems, and promise even more rapid detection and suppression than the Firetrace system. It is hoped that future JASP and JLF efforts will provide the opportunity to evaluate these technologies to allow added competitive solutions to be identified for aircraft fire vulnerabilities. ■



Figure 2 JASP SPEX Project Testing of the Firetrace System

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Calendar of Events

MAR

8th Annual Missile Defense Conference and Exhibit

22–24 March 2010
Washington, DC

JASP Spring PMSG P&W

23–25 March 2010
West Palm Beach, FL

Personnel Recovery Conference

29 March–1 April 2010
Arlington, VA

Military Air Assets Exhibition & Conference (MAASEC)

29 March–1 April 2010
Jacksonville, FL

ATEDS

30 March–1 April 2010
San Diego, CA

APR

JLF-Air Mid Year Review

April 2010
Aberdeen Proving Ground, MD

SpecOps Warfighter EAST 2010

12–15 April 2010
Fayetteville, NC
<http://defensetradeshows.com/specops-warfighter-expo-east-2010/#>

51st AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference

12–15 April 2010
Orlando, FL

11th Annual Science & Engineering Technology Conference/DoD Tech Exposition

13–15 April 2010
North Charleston, SC

AAAA Annual Convention

14–17 April 2010
Fort Worth, TX
<http://www.quad-a.org>

DoD Electromagnetic Environmental Effects (DOD E3)

27–28 April 2010
Tampa, FL
<http://www.fbcinc.com/dode3>

JCAT TWES

27–29 April 2010
Eglin AFB, FL

Global Explosive Ordnance Disposal Conference & Exhibition

27–30 April 2010
Fort Walton Beach, FL

MAY

Air Vehicle Survivability Workshop

May 2010
Boston, MA

NDIA Workshop

May 2010
Alexandria, VA

2010 Aircraft Combat Survivability Short Course

4–7 May 2010
Monterey, CA
<http://bahdayton.com/surviac>

SpecOps West 2010

10–12 May 2010
Ft. Lewis, WA
<http://defensetradeshows.com/specops-west-warfighter-expo-2010>

AHS International 66th Annual Forum & Technology Display

11–13 May 2010
Phoenix, AZ
<http://www.vtol.org>

JUN

JMUM 2010

15–17 June 2010
Colorado Springs, CO
<http://bahdayton.com/surviac>

2010 Special Operations Forces Industry Conference

15–17 June 2010
Tampa, FL

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

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Herndon, VA 20171