

# 12

SPRING ISSUE

published by the  
Joint Aircraft  
Survivability  
Program Office

# AIRCRAFT SURVIVABILITY

## LIVE FIRE TEST AND EVALUATION AND JOINT LIVE FIRE

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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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The only systematic live fire testing performed on aircraft was the Test and Evaluation of Aircraft Survivability (TEAS) in the early 1970s. TEAS grew out of the Southeast Asia conflict in which the large number of aircraft losses made it clear that survivability (i.e., vulnerability reduction considerations) did not receive sufficient emphasis in their designs. TEAS was a tri-service program to evaluate the vulnerability of the F-4, A-7, and AH-1 aircraft, develop vulnerability reduction concepts for those aircraft, and apply the knowledge gained to future aircraft. Following TEAS, funding emphasis moved from evaluation by full-scale live fire testing toward evaluation by analysis (i.e., computer modeling) until in the early 1980s when the services recognized the value of ballistic testing as a developmental design tool and started aggressive vulnerability test programs, most notably for the V-22 and F/A-18.

## 13 JSF FULL UP SYSTEM LEVEL TESTING

*by Chuck Frankenberger*

To fulfill the congressionally mandated Live Fire Test (LFT) activity, the Joint Strike Fighter (JSF) program is conducting full up system level (FUSL) testing on one JSF variant, and will conduct variant unique testing on production representative structural test articles. Aircraft 2AA:0001, (AA-1), a Conventional Take-Off and Landing (CTOL) Air Force variant, was selected as the FUSL test article and was used in conjunction with pilot-in-the-loop simulator testing to obtain an overall assessment of the pilot/aircraft's ability to maintain safe flight after ballistic damage. The test program was designed to evaluate the aircraft systems for synergistic effects.

## 16 CH-53K LIVE FIRE TEST AND EVALUATION

*by Marty Kramer*

The CH-53K is the next generation, state-of-the-art, heavy lift rotorcraft platform currently under development for the United States Marine Corps (USMC). As a new acquisition and untested system, the CH-53K will undergo Live Fire Test and Evaluation (LFT&E) to determine its overall vulnerability against threats likely to be encountered in combat. This article discusses aspects of the CH-53K, its requirements, capabilities, survivability features (vulnerability and susceptibility reduction), and the systems engineering approach taken to ensure the CH-53K is the most advanced, effective, and survivable helicopter possible for the war fighter.

## 22 EXCELLENCE IN SURVIVABILITY— MARTIN N. KRAMMER

*by Joseph Manchor*

The Joint Aircraft Survivability Program JASP takes pleasure in recognizing Mr. Martin N. Kramer for Excellence in Survivability. “Marty” is a project engineer with the Combat Survivability Division of the Naval Air Systems Command (NAVAIR), China Lake, CA. Marty is currently the lead for the CH-53K Live Fire Test and Evaluation (LFT&E) Program. However, his previous experience as the Lead Range Engineer for the Weapons Survivability Laboratory (WSL) is particularly noteworthy, as he was instrumental in the design of multiple new test capabilities that vastly improved the realism and fidelity of LFT&E. Throughout his career, he has provided support through the design and development of advanced test fixtures for nearly every LFT&E program conducted to date at the WSL, including A-12, P-7, F/A-18E/F, V-22, AH-1Z, UH-1Y, MH-60R/S, and F-35.

## 24 LIVE FIRE TESTING A LEGACY WING

*by John Kemp and Lisa Woods*

The C-5 has been subjected to a much needed modernization program in the last decade. One phase of this modernization was the Reliability Enhancement and Re-engining Program (RERP). Because of this modernization, it was determined by the Office of the Secretary of Defense (OSD) that the C-5M aircraft was a covered system for Live Fire Test and Evaluation (LFT&E). One of the areas of interest was vulnerability to dry bay fires for the C-5 legacy wings. The C-5 RERP program addressed these questions.

## 33 NDIA AIRCRAFT SURVIVABILITY SYMPOSIUM

*by Walt Whitesides*

On Tuesday–Thursday, November 1–3, 2011, the annual NDIA Aircraft Survivability Symposium, “Survivability in a Complex Threat Environment,” was held at the Admiral Kidd Catering and Conference Center at the Fleet Anti-Submarine Warfare Training Center in San Diego, CA. Over 300 people attended this year’s event. Tuesday was devoted to two tutorial sessions – Fundamentals of Aircraft Survivability and Radar Cross Section Reduction. That evening, attendees had the opportunity to network at an informal reception hosted at the Hyatt Regency Mission Bay Spa & Marina.

The formal symposium was held on Wednesday and Thursday, with a Keynote Address on each day. BG Kevin Mangum, USA, US Army Special Operations Aviation Command and Mr. Paul Meyer, Northrop Grumman Corporation presented their perspectives on the symposium theme. Each address was followed by numerous speakers who provided threat briefings, combat lessons learned, research and development updates, methodologies for countering threats, and future requirements. A Poster Papers and Display room was also offered to all attendees during symposium hours. On Wednesday evening, symposium attendees boarded the Lord Hornblower for a dinner cruise of San Diego Harbor.

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Distribution Statement A:  
Approved for public release;  
distribution unlimited, as submitted  
under OSD/DOT&E Public Release  
Authorization 128-1077.

## CH-53K HELICOPTER SYSTEMS ENGINEERING TEAM RECEIVES DOD TOP 5 PROGRAMS AWARD

The CH-53K Helicopter Systems Engineering Team won the Department of Defense (DoD) Systems Engineering Top 5 Programs Award at the annual National Defense Industry Association (NDIA) Systems Engineering Conference Award Luncheon in San Diego, CA on 26 October 2011. The NDIA presented the prestigious award to the CH-53K Helicopter Systems Engineering Team, consisting of both Naval Air Systems Command (NAVAIR) and Sikorsky Aircraft Corporation engineers, in recognition of excellence in the application of systems engineering practices resulting in highly successful DoD programs, as exemplified by their 2010 performance. The evaluation team, made up of senior individuals from across the DoD, felt that the CH-53K program's efforts are clearly in keeping with the award's intent to honor programs that "demonstrate successful implementation of systems engineering best practices resulting in program success," said Col Donald W. Robbins, chairman of the Top 5 Awards Evaluation Team.

"The CH-53K Systems Engineering Team worked hard over the past few years, and we are seeing the benefits of a disciplined and systematic approach," said Col Robert Pridgen, USMC, H-53 Heavy Lift program manager. "The Systems Engineering Team set the foundation for us to deliver a marinized, heavy-lifting helicopter that meets the future war fighting requirements of the Marine Corps, sustains the expeditionary capabilities, and is supportable,

maintainable, and reliable throughout its entire lifecycle." Col Pridgen sent his congratulations to his systems engineering team, which includes survivability engineers and analysts from both government and industry. Survivability is a key part of the systems engineering effort, which includes two of seven key performance parameters (KPP) and is integrated into the component, subsystem, and system level design. The program is now moving into the test phase, and planning is underway for a comprehensive live fire test program, which will begin in FY13.

The Navy survivability team included Rich Gardner, Marty Krammer, Kathy Russell, and Ralph Mattis from NAVAIR. The industry survivability team members include Dustee Hata, Dale Humphries and Alan Coyne from Sikorsky, and Nick Gerstner from SURVICE Engineering. The government team, with SURVICE support, also received two PMA-261 Gold Star Awards for supporting a critical systems armor design for the CH-53E, which was an urgent need program from our warfighters.

Congratulations to all for a job well done.

## EXPLODING FUEL TANKS BY RICHARD L. DUNN

Anyone with an interest in military aviation, aircraft technology, pilot safety, or the World War II Pacific air war cannot help but be fascinated by the depth and breadth of information in *Exploding Fuel Tanks* by Richard L. Dunn.

Subtitled "the saga of technology that changed the course of the Pacific air war," this book dives right in to the state of the

art of aircraft fuel tank protection up to 1940 and then explores developments in fuel tank protection technology and lessons learned in the Pacific during World War II. He devotes a full chapter to a case study of the air war over Midway.

Using declassified and extensive World War II research archives, Dunn provides an "extremely readable and convincing" account, according to one reviewer, that fascinates even "those who are not specialists," according to one reviewer.

Another reviewer praised Dunn's ability to weave "seemingly disparate subjects (rubber, synthetics, bullets, engine power, aluminum, steel, etc.)" into the central theme of how research in different parts of the world evolved to protect pilots and advance the technology of air combat.

Quoting the Army Air Corps hymn ('we live in fame or go down in flame!'), Daniel Ford, author of *Flying Tigers: Claire Chennault and His American Volunteers, 1941-1942*, credits Dunn for telling the "... story of how Britain and Germany developed the first 'crash proof fuel tanks,' and how other countries, including the US and Japan, scrambled to catch up, to save their pilots from death or disfiguring burns."

Through Dunn's research, readers learn that the Soviets developed pilot and fuel tank protection technology as early as 1934, using a 9mm-thick steel alloy plate to protect the pilot's head and a system of capturing and cooling engine exhaust gases, then injecting them into aircraft fuel tanks to reduce the oxygen content of vapors left in the tanks as gas was consumed.

Dunn served as general counsel for the Defense Advanced Research Projects Agency, worked for the National Aeronautics and Space Administration, practiced law, and served on active duty as a member of the Judge Advocate General corps of the US Air Force. A former senior fellow at the University of Maryland, Dunn has done extensive research in national security, acquisition issues, private-public partnerships, and "contractors on the battlefield."

A possibly unanticipated benefit for readers is the fascinating look at the technical articles and illustrations from sources as disparate as "Flight Through German Eyes," a 1941 translation from the German journal *Luftwissen*; illustrations of self-sealing fuel tank bullet penetration from a US Army technical manual; and photographs of workers preparing tanks for test and production at the B.F. Goodrich factory. These articles and drawings of the period, supplied not only from US sources but from European

and Japanese archives, bring life to the subject and complement Dunn's well-researched text.

Called a "must read for all World War II enthusiasts," *Exploding Fuel Tanks* is available from Perfect Paperback through <http://www.google.com>; <http://www.ExplodingFuelTanks.com>; or from Amazon.com. The first chapter is available to read as a PDF. **ASJ**

## JCAT CORNER

by CAPT Thomas P. Mayhew, USN



The Joint Combat Assessment Team (JCAT) continues to support Army and Marine Corps aviation operations in Afghanistan by providing critical forensic analysis of hostile fire against US combat aircraft. The team is anticipating a year of change in 2012 as the American forces begin to draw down, turn over operations to the Afghan government, and reconstitute equipment and personnel after over 10 years of war.

This past year marked a significant time of contribution, transition, and change for JCAT. The forward-deployed team conducted 134 assessments of hostile fire damage during 2011. CDR Dan Boscola turned over the JCAT Liaison Officer (LNO) role to CDR Steve Mainart in April, and CDR Mainart handed over the reins to LCDR Shawn Denihan in November. Each of these officers were on their second JCAT deployment, having served in Operation Iraqi Freedom in the 2004–2007 timeframe. They were assisted in supporting 2nd Marine

Aircraft Wing (MAW) in Helmand Province by LTs Jim McDonnell, Khanh Luu, and Jason Michaels. The Air Force provided assessor support to the Army 10th and 101st Combat Aviation Brigades at Bagram and Kandahar, respectively, by CAPTs Cody Gatts, Dan Carroll, David Liu, and William Vu. CW5 Bobby Sebren provided JCAT support and guidance in his role as the TACOPs officer at 10th CAB in Bagram and will return to Ft Rucker and relieve CW5 Brendan Kelly as the Army JCAT service lead.

The Afghanistan JCAT operation was supported by a full-time team of two Navy officers assigned to 3rd MAW at Marine Corps Air Station Miramar, CA, and one Air Force officer at Wright-Patterson Air Force Base, OH. This CONUS team provided predeployment training, mobilization support, analytical reach-back support, and direct links to the aircraft survivability experts at Naval Air Systems Command and Air Force Electronic Systems Command. CAPT Tom

Mayhew has served as the NAVAIR/JCAT LNO at 3rd MAW since December 2008 and was joined late last year by LCDR Scott Quackenbush, who was relieved by CDR Chad Runyon in June. Lt Col Jeff Ciesla served in the Air Force LNO role from late 2009 until this past summer when he was relieved by Lt Col Norm White.

The CONUS team supported the annual JCAT assessor training at Ft Rucker, AL, China Lake, CA, and Eglin Air Force Base, FL. They participated in making upgrades to the Combat Damage Incident Reporting System (CDIRS) data repository that is maintained by the Survivability Information Analysis Center (SURVIAC) at Wright-Patterson Air Force Base. The team supported the Air Combat Data Reporting (ACDR) initiative commissioned by the Undersecretary of Defense for Acquisition, Technology, and Logistics, to create a Department of

*continued on page 32*

# JOINT LIVE FIRE—AIRCRAFT SYSTEMS (JLF-AIR)

Live Fire Testing and Evaluation's (LFT&E) Older Brother

by Rick Sayre

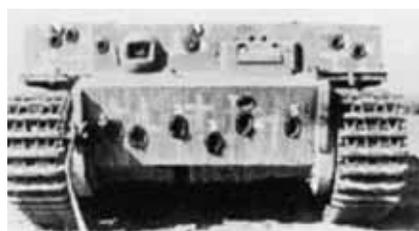


Live fire testing in the US goes at least as far back as early WWII, when live fire tests demonstrated the M2-series light tanks could be defeated by .50 cal armor piercing (AP) machine gun fire. It continued through the 1950s, culminating in the Canadian Armament Research and Development Establishment (CARDE) trials in 1959. CARDE—the last comprehensive series of live fire tests on armored targets looked at a number of generic shaped charge warheads in an attempt to assess their lethality against enemy targets. In the 25 years between CARDE and the start of Joint Live Fire (JLF) in 1984, there were only isolated instances of live fire testing on armored vehicles (most notably, the GAU-8 lethality tests for the cannon installed on the A-10 Thunderbolt II).

On the aircraft side, the only systematic live fire testing was the Test and Evaluation of Aircraft Survivability (TEAS) in the early 1970s. TEAS grew out of the Southeast Asia conflict in which the large number of aircraft losses made it clear that survivability (*i.e.*, vulnerability reduction considerations) did not receive sufficient emphasis in their designs. TEAS was a tri-service program to evaluate the vulnerability of the F-4, A-7, and AH-1 aircraft, develop vulnerability reduction concepts for those aircraft, and apply the knowledge gained to future aircraft. Following TEAS, funding emphasis moved from evaluation by full-scale live fire testing toward evaluation by analysis (*i.e.*, computer modeling) [1] until in the early eighties



**Figure 1** M2-series light tank rolls past the Capitol building in the annual Army Day Parade. Washington, D.C., 6 April 1939.



**Figure 2** Live fire testing with a 6-pounder (57mm) anti-tank gun against a German Tiger I tank during WWII.

when the services recognized the value of ballistic testing as a developmental design tool and started aggressive vulnerability test programs, most notably for the V-22 and F/A-18.

## ORIGINS IN CONTROVERSY — ENTER THE M2 BRADLEY

Because of concerns over the survivability of US weapon systems, the Office of the Secretary of Defense (OSD) set up a live-fire test program to test the lethality of US weapons against Soviet vehicles and determine the vulnerabilities of US vehicles to Soviet weapons. The Joint Logistics Commanders endorsed this proposed test program in December 1983, and the JLF test charter was signed by the Director, Defense Test and Evaluation in March 1984. One of the first and perhaps most controversial live fire tests involved the M2 Bradley. [2]

The M2 Bradley live fire test was conducted under substantial scrutiny by Congress and the national media. The initial M2 Bradley live fire tests began as a JLF program (Phase I) with Phase II conducted by the Army with OSD oversight. In a 1986 report reviewing the Army's Phase I report to Congress, the Government Accounting Office (GAO) found the M2 Bradley's Phase I test results left a number of questions about the Bradley's vulnerability unanswered. Insufficient information, limited vulnerability information from updated models, and no expected casualties/catastrophic



**Figure 3** M2 Bradley Undergoing Live Fire Testing

kills for missile or projectile hits on all the Bradley's vulnerable areas were cited as the factors for their assessment.

The GAO further found, the test conditions that the Army established influenced the outcome of the tests in such a manner that the results indicated less vulnerability than should reasonably be expected in combat. These included avoidance of shots that could have directly penetrated stowed ammunition, simulated threat weapons were not, in all cases, typical of the latest Soviet weapons deployed, and only the cavalry version of the Bradley was tested. Since the cavalry version carries fewer troops than the infantry version, casualty rates would have been higher, on the average, had the infantry version been used, given the same number of hits in identical areas.

## LIVE FIRE TESTING TODAY

Fast forward 25 years and both test programs emphasize the need for system evaluations based on realistic survivability and lethality testing. Realistic survivability testing means using munitions likely encountered in combat and with respect to a weapon system, loaded or equipped with all dangerous materials (including flammables and explosives) that would normally be on board in combat. The primary differences between the two types of live fire testing are the funding source, the point in the acquisition cycle testing takes place, and legislative oversight. This focus on live fire survivability testing have benefitted our air, ground and sea platforms to where current platforms are able to survive damage levels lethal to earlier aircraft types.

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

Live fire testing is a statutory requirement for new acquisition systems under US Code, Title 10, Section 2366. A statutory requirement for about a quarter of a century, it stipulates covered systems [3] may not proceed beyond low-rate initial production until realistic survivability or lethality testing of the system is completed and reported. It further specifies testing must be carried out sufficiently early in the development phase to allow any demonstrated design deficiency to be corrected in the design of the system, munitions, or missile before proceeding beyond low-rate initial



**Figure 4** A P-8A Poseidon flies near the Chesapeake Bay in preparation for another test event. (US Navy photo)

production. The costs of all tests required under this statute are paid by the system being tested.

In the February 2011 Designation of Programs for Office of the Secretary of Defense Developmental, Operational and Live Fire Test and Evaluation Oversight, 116 programs were listed as having a live fire requirement. Tables 1 and 2 show the breadth of systems covered by LFT&E as outlined in the February 2011 Oversight List.

### Joint Live Fire (JLF)

JLF tests fielded systems, rather than systems undergoing development during acquisition. Administratively, it is managed according to the domain where the system operates. These domains are ground, sea, and air. Most importantly, it complements LFT&E through testing of systems that pre-date LFT&E or do not have an LFT&E requirement or systems that completed LFT&E, but something changed or was limited in some way.

In particular, the goal of the Joint Live Fire – Aircraft Systems (JLF-Air) program is to identify vulnerable areas in current



**Figure 5** AH-1Z Cobra

aircraft platforms, understand the mechanisms involved in threat /aircraft interaction, and provide this information to the aircraft survivability community to improve aircrew and aircraft survivability. The remainder of this article focuses on how JLF-Air does this and complements LFT&E.

- ▶ PRE-DATE OR NO REQUIREMENT
  - Understand and improve the system
  - Provide baseline for planned upgrades that might require LFT&E
  - Develop test technologies to increase LFT&E realism
  - Evaluate unmanned platforms
- ▶ CHANGED OR LIMITED
  - Threat or mission has changed
  - Test articles/threats not available
  - Limited by cost or practicality
  - Introduced vulnerabilities
  - Reduced vulnerability/enhanced lethality verified by testing

**Table 1** LFT&E Oversight Programs by Service

Military Service	Programs with LF Requirement...	...of which are an aircraft platform	% that are aircraft by Service
USAF	18	12	67%
Army	48	6	13%
Navy (inc. USMC)	49	10	20%
Other (MDA)	1	1*	100%

\*BMDS includes Airborne Laser Testbed (ALTB), and Airborne Infrared (ABIR)

**Table 2** Selected aircraft programs on the February 2011 oversight list.

Selected Aircraft Programs on the February 2011 Oversight List	Common Name	Service
<b>Rotorcraft – Attack/Observation</b>		
<b>AH-64</b> Apache Block III	AB3	USA
<b>AH-1Z</b> Viper (a.k.a. “Zulu”)	AH-1Z	USN
<b>OH-58</b> Kiowa Warrior Upgrade	KWU	USA
<b>MH-60S</b> Multi-Mission Combat Support Helicopter	MH-60S	USN
<b>Rotorcraft – Transport</b>		
<b>UH-60M</b> Black HAWK UPGRADE -Utility Helicopter Upgrade Program	UH-60M	USA
<b>MH-60R</b> Multi-Mission Helicopter Upgrade	MH-60R	USN
<b>CH-53K</b> Heavy Lift Replacement Program	CH-53K	USN
Common Vertical Lift Support Platform	CVLSP	USAF
<b>HH-60</b> Recap (formerly known as Combat Search & Rescue Replacement )	CSAR-X	USAF
Joint Future Theater Lift Concept	JFTLC	USA
<b>CV-22</b> OSPREY – Joint Advanced Vertical Lift Aircraft	OSPREY CV-22	USN
Presidential Helicopter Fleet Replacement Program	VXX	USN
<b>Fixed Wing – Transport/Tanker</b>		
<b>C-130</b> Aircraft Avionics Modernization Program	C-130 AMP	USAF
<b>C-5</b> Aircraft Avionics Modernization Program	C-5 AMP	USAF
<b>C-5</b> Aircraft Reliability Enhancement and Re-engining Program	C-5 RERP	USAF
<b>C-27J</b> (JCA -Joint Cargo Aircraft)	C27J (JCA)	USAF
<b>HC/MC 130</b> Recapitalization	HC/MC	USAF
<b>KC-130J</b> with Harvest Hawk	KC-130J	USN
<b>KC-X</b> Tanker Replacement Program	KC-X	USAF
Light Mobility Aircraft	LiMA	USAF
<b>Fixed Wing – C4ISR</b>		
<b>E-4B</b> National Airborne Operations Center Aircraft Replacement Program	E-XX	USAF
Enhanced Medium Altitude Recon Surveillance System	EMARSS	USA
USN Unmanned Carrier Launched Airborne Surveillance and Strike System	USN UCLASS	USN
<b>P-8A</b> Poseidon Program	P-8A	USN
Presidential Aircraft Recapitalization Program	PAR	USAF
<b>Fixed Wing – Fighter/Attack</b>		
<b>F-35</b> Lightning II Joint Strike Fighter (JSF) Program	JSF	USAF
<b>Fixed Wing – C4ISR</b>		
Joint and Allied Threat Awareness System	JATAS	USN

## Understand and Improve the System

Understanding the vulnerability of already fielded systems has been a primary focus of previous JLF-Air efforts. Many of these systems pre-date LFT&E. Test programs for various full-up or component tests have been completed for the platforms listed in Table 3.

Now that LFT&E has been around for 25 years, many of the currently fielded systems have already conducted live fire testing under Title 10 statutory requirements. As a result, JLF-Air presently does not have any future full-up tests planned and expects to focus on providing LFT&E support primarily through improved test technologies, evaluation of vulnerability reduction

**Table 3** List of aircraft platforms tested under JLF-Air

Fixed Wing			Rotorcraft	
Fighter/Attack	Transport/Tanker	C4ISR	Attack/Observation	Transport
A-10	C-17	P-3	AH-1	CH-46
AV-8	TF-39/CF-6	MQ-1	AH-64	CH-47
F-14	C-27		OH-58	CH-53
F-15	C-130		RAH-66	UH-60
F-16			Foreign	
F/A-18				
Foreign				



**Figure 6** F/A-18 Fuel System Joint Live Fire Testing



**Figure 7** Ch-53E Tail Rotor System Joint Live Fire Ballistic Testing in 2006.



**Figure 8** Large turbofan engine hanging on its test fixture prior to MANPADS testing. Note the size of engine and test fixture compared to the two people in front of the engine. Note the size of engine and test fixture compared to the two people in front of the engine. (US Navy Photo)

enhancements, testing new and emerging threats, and providing baselines for programs with upgrades that may require a live fire test.

- PROVIDE BASELINE FOR PLANNED UPGRADES THAT MIGHT REQUIRE A LIVE FIRE TEST

Under JLF-Air project T-09-13, Large Engine Man Portable Air Defense System (MANPADS) Vulnerability, two MANPADS were shot into operating jet engines to investigate engine-nacelle fires, uncontained engine debris, and the ability to maintain controlled flight and safely land with damaged engines and airframes. As the extent of the set-up in

Figure 8 shows, every effort was made to have the most realistic test conditions possible to include power settings, airflow, MANPADS impact velocity, detonation conditions, and shotline selection.

This testing will assess large engine vulnerability to MANPADS, validate engine MANPADS modeling procedures and ultimately provide a foundation for MANPADS test requirements in future Test and Evaluation Master Plans (TEMP). It also will improve the credibility of aircraft vulnerability assessments and



**Figure 9** Engine maintenance specialists position an upgraded PT6A-68 turboprop engine in a T-6 Texan II aircraft at Randolph Air Force Base, Texas. (US Air Force photo by Steve Thuro/Released) 091214-F-SS509-001

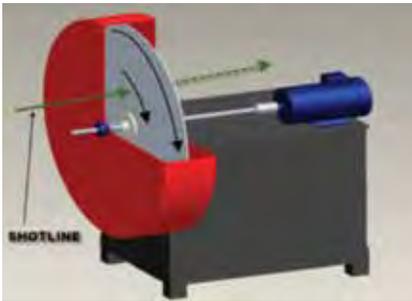
provide input to the Large Commercial Derivative Aircraft program and KC-X LFT&E.

The PT6 engine is the power plant for a majority of Light Air Support (LAS) aircraft, Light Attack Armed Reconnaissance (LAAR) aircraft, and Light Mobility Aircraft (LiMA) proposals to support the Afghanistan war effort. Currently LiMA is the only one with an LFT&E requirement, but a vulnerability baseline is warranted for this engine due to the fact that most US aircraft that fly with PT6 engines have little or no protection from ballistic threats.

The PT6 engine was not designed with vulnerability reduction features in mind. There are several potential vulnerability issues, including critical component vulnerability, engine fire potential, and the possibility of uncontained engine debris that needs to be evaluated. Starting in FY12, JLF-Air plans to baseline the vulnerability of the PT6 turboprop family of engines and identify those vulnerability reduction measures discovered.



**Figure 10** Frame from a high-speed film showing a MANPADS missile passing through an aluminum target panel. Note the length of the rocket motor plume. (US Army Photo)



**Figure 11** Test fixture developed under the JLF project T-10-03, V50 Tests of Yawed Projectiles.

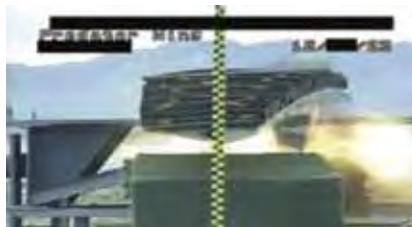
### ► INCREASING LFT&E REALISM

Supersonic Rocket on a Rope (SROAR) is a proposed method of controlling missile impact conditions to allow for precise shotlines in LFT&E and/or JLF testing. Under project T-09-05, SROAR Dynamic Impact Testing, the JLF program is funding a series of test phases to demonstrate the viability of this test method, culminating with a demonstration shot into a realistic aircraft target. Figure 10 shows a test from earlier this year at Redstone Arsenal, AL.

A second JLF project looks to determine the yaw angle influence on projectile residual velocity and shotline direction. Vulnerability modeling typically does not consider projectile yaw angle when considering penetration and shotline effects. The results will provide immediate feedback as to the accuracy of analytical tools used in LFT&E. Figure 11 shows the test fixture developed under the JLF project T-10-03, V50 Tests of Yawed Projectiles. The gray disk is the metal target-spinning at a speed to replicate the proper yaw angle for a typical encounter with a fixed wing fighter type target.



**Figure 12** An MQ-9 Reaper sits on a ramp in Afghanistan. Larger and more powerful than the MQ-1 Predator, the Reaper is designed to go after time-sensitive targets with persistence and precision, and destroy or disable those targets. (Courtesy Photo) 070931-M-5827M-116



**Figure 13** An unspecified threat hits the Predator wing

### ► EVALUATE UNMANNED PLATFORMS

Many of the findings from JLF-Air manned aircraft tests are applicable to unmanned platforms, but due to the UAV mission, unique live fire survivability considerations exist. These include, but are not limited to, small size means limited separation, low cost means limited redundancy, and unmanned means less stringent design philosophies. Previous JLF-AIR testing looked at the vulnerability of unmanned platforms' engine, fuel system, and wing structure.

### ► THREAT OR MISSION HAS CHANGED

Back when the F-14 Tomcat was just entering the fleet as the Navy's premier air interceptor, the Tomcat did not need to worry about land based surface-to-air



**Figure 14** F-14B Tomcat aircraft of Fighter Squadron 143 (VF-143), the Pukin' Dogs, dropping a Mark 83 1,000 pound bomb over the bombing range. (Photo by LTJG Stephen P. Davis) DN-SC-95-01065

threats since "it would never fly over hostile land forces". Fast forward thirty years and you had the "Bombcat" flying bombing missions over Afghanistan – a mission never envisioned during the early days of the F-14 program. With a new mission and the potential for new land-based threats, the F-14, despite having just been retired from service, still serves as a good example of an aircraft with a changed mission/threat that would be considered for JLF testing.

The Rocket Propelled Grenade (RPG) is an example of a threat employed differently than its intended design. Originally developed as an anti-tank or anti-personnel weapon, the RPG is being used as an anti-helicopter weapon by hostile forces in Afghanistan. In a recent incident in Afghanistan, a helicopter was damaged in a manner uncharacteristic of previous incidents. The Joint Combat Assessment Team (JCAT) requested JLF-Air support by providing threat-target



**Figure 15** This Afghan Military Forces (AMF) soldier carries this RPG loaded and ready to fire. Weapons are a common sight in Afghanistan, less common however are uniforms. Lack of uniforms makes it difficult to determine which group their loyalty is to. (US Army Photo by Sgt. 1st Class Freddy E Gurwell) 020704-A-JX473-129

characterization data for their incident investigation to address their concerns about a potential new threat to helicopters. The results from these tests allowed JCAT to confidently understand the engagement condition and provide the proper recommendations to leadership.

► LIMITED BY COST OR PRACTICALITY

A current JLF-Air focus is quantifying MANPADS damage effects against aerospace structures and updating our modeling and simulation capabilities against these prolific threats. MANPADS have been a threat since the late 1960s but are seldom included in TEMPs or considered for LFT&E events. Over this same timeframe, we realized great strides in reducing the vulnerability of US aviation platforms to the point that current platforms demonstrate tolerance to MANPADS hits. This damage tolerance along with MANPADS increasing proliferation makes it critical to develop efficient test capabilities and a credible modeling capability to support future LFT&E strategies requiring MANPADS.

One JLF-Air project currently executing is collecting MANPADS fragment/debris and blast data of sufficient quality to improve the accuracy and credibility of MANPADS threat models used by LFT&E to assess and predict aircraft vulnerability. Blast and fragment/debris data collection is complete with debris penetration testing occurring this fiscal year. When all complete, an updated

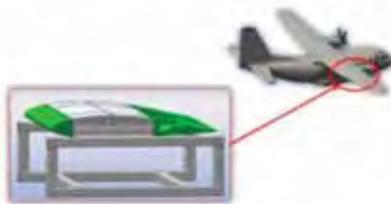


**Figure 16** Manpads Prior To Fragment/Debris Test (US Army Photo)

MANPADS modeling and simulation capabilities will be available to support future LFT&E.

► REDUCED VULNERABILITY/  
ENHANCED LETHALITY VERIFIED  
BY TESTING

Historically, fire is the largest contributor of vulnerable area in aircraft vulnerability assessments. Reducing fire vulnerability observed during Joint Cargo Aircraft (JCA) LFT&E is a cost effective way to increase its survivability. Under JLF-AIR project T-10-02, Dry Bay Fire Vulnerability, the feasibility of implementing selected passive dry bay fire extinguishing technologies within the JCA wing leading edge and trailing edge dry bays were demonstrated.



**Figure 17** Figure Showing the Portion of the Wing Tested During These Tests (US Air Force Photo)

## CONCLUSION

Live fire testing has been around for many years. After its origins in controversy in 1984, JLF, along with the statutorily required LFT&E, have played important roles in providing our forces the best weapon systems possible. JLF-Aircraft Systems (JLF-AS) continues to play an important role by complementing LFT&E efforts. Primarily through improved test technologies, evaluation of vulnerability reduction enhancements, testing new and emerging threats, and providing baselines for programs upgrades. **ASJ**

## References

- [1] Excerpted from the Report to the Chairman, Subcommittee on Seapower and Strategic and Critical Materials, Committee on Armed Services, House of Representatives, Live Fire testing, Evaluating DoD's Programs, August 1987. GAO/PEMD-87-17
- [2] A dark comedy describing the development of the M2 Bradley was made into a movie based on the book by Col James Burton, USAF (ret.). The Pentagon Wars released in 1998 by HBO stars Kelsey Grammer and Cary Elwes as James Burton.
- [3] For survivability testing, a vehicle, weapon platform, or conventional weapon system that— (i) includes features designed to provide some degree of protection to users in combat; and (ii) is a major system as defined in section 2302 (5) of this title; or any other system or program designated by the Secretary of Defense for purposes of this section.

# JSF FULL UP SYSTEM LEVEL TESTING

## F35 Flight Critical Systems Test

by Chuck Frankenberger

To fulfill the congressionally mandated Live Fire Test (LFT) activity, the Joint Strike Fighter (JSF) program is conducting Full Up System Level (FUSL) testing on one JSF variant, and will conduct variant unique testing on production representative structural test articles. Aircraft 2AA:0001, (AA-1), a Conventional Take-Off and Landing (CTOL) Air Force variant, was selected as the FUSL test article and was used in conjunction with pilot in the loop simulator testing to obtain an overall assessment of the pilot/aircraft's ability to maintain safe flight after ballistic damage. The test program was designed to evaluate the aircraft systems for synergistic effects.



As engineers, we do our best to incorporate lessons learned from past projects into design of the next program. However, there remain many unknowns even when leveraging this knowledge base. As the trend continues toward highly integrated aircraft systems compared to the aircraft they are replacing, the unknown reaction of these integrated systems to ballistic damage is not well understood. What are the interactions between systems given ballistic damage? Does damage to one system affect the performance of other systems? The primary benefit of FUSL testing is the ability to monitor each of the aircraft systems simultaneously to capture transient behaviors and interactions across systems. During aircraft development, components are tested

individually, then as individual systems, then as integrated systems. The JSF LFT program has followed this developmental test approach, testing components early on in the program and system level testing on AA-1. Live Fire testing is required at the system level to take into consideration the non graceful degradation of components/systems as a result of ballistic damage. Damage to one system should not adversely affect other systems. For systems with redundant or backup capabilities, damage should remain isolated and should not affect the ability to transition into backup configurations.

AA-1 was the first produced JSF CTOL aircraft. AA-1 flew to China Lake on 17 December 2009, its 91st flight, and had accumulated 125.9 flight hours. AA-1 had started production prior to the program going through a significant weight reduction effort in 2004 – 2005. This weight reduction activity resulted in major changes in the airframe structure, which made most of the AA-1 structure non-production representative. The flight critical systems tested in AA-1 are

functionally representative of F35 production aircraft. In some cases, there are slight variations in component location and configuration. These variations were taken into consideration during the test program to provide production representative testing.

The objective of this test series was to evaluate flight critical systems response to ballistic damage. Flight critical systems include the Flight Control System (FCS), Vehicle System Network (VSN), Electrical Power System (EPS), and the Power and Thermal Management System (PTMS). A secondary objective was to verify component failure modes used previously in controlled damage test scenarios. In these tests, Lockheed's pilot-in-the-loop Vehicle Integration Facility (VIF) and Vehicle System Integration Facility were used to evaluate pilot response and aircraft handling qualities after simulated aircraft damage.

Test participants include China Lake Weapons Survivability Lab (WSL) test personnel, Lockheed Martin (LM) LFT team members, LM IPT Subsystem

experts, Wright Patterson JSF LFT team members, OSD/LFT&E, and IDA representatives.

## TEST APPROACH

This test series was conducted in a way to best represent a combat mission. Test procedures from battery on, engine start, throttle to MIL, gear up...to gear down, engine off, were defined in each run plan. Aircraft systems were in a flight configuration. A critical part of the test program was the ability to move the flight controls and to appropriately load the electrical power system. To do this, surface positions were recorded in the VIF during pilot in the loop testing and used as a flight control script to move the control surfaces at rate during AA-1 ballistic testing.



The aircraft was operated remotely using its internal systems. Pilot interfaces were controlled remotely through a Compact Remote Input/Output (RIO) control system developed by China Lake Weapons Survivability engineers. This includes pilot functions such as the battery switch, engine start switch and gear handle. Cockpit displays were provided through a software package developed by Lockheed Martin. This included displaying Integrated Cautions and Warnings (ICAWs). System monitoring was also provided through software packages used in the design and test of the aircraft during initial flight qualifying check outs. This provided test engineers



with a very good view of the aircraft system performance during test events. Systems monitored during test included EPS, PTMS, and FCS.

Test sequencing was defined to balance the need to keep the aircraft in a FUSL configuration as long as possible to acquire system level results, and the need to address high priority tests that would take the aircraft out of a FUSL configuration. Early low risk tests were conducted on wire harnesses and cooling ducts that were easily repaired. These early tests verified that the response of the EPS and PTMS systems compared favorably to the response seen in the pilot-in-the-loop simulator tests. Testing progressed to shooting various line replaceable units as part of the FCS and EPS. Spares components were used to reconstitute the test article. High priority tests were conducted after the replaceable component shots were completed. These tests include a Man Portable Air Defense System (MANPAD) shot, an HEI shot into a fuel tank, a fragment shot into the integrated power package (IPP) rotating machinery, and a polyalphaolefin (PAO) (avionics cooling fluid) fire test. Close attention was given to the sequence in which the aircraft systems were degraded. Test sequencing was based on system dependencies and facility integration requirements. As an example, to conduct fire detection testing on the aircraft, the three Vehicle Mission Computers (VMC) and all RIO's needed to be operational to evaluate fire detection capability. The fire detector inputs are spread across the RIOs and the RIOs

spread across the VMC bus channels, and the detection software housed in the VMCs. These systems were required to be operational until the fire detection capability was no longer needed.

## TEST RESULT

Ballistic testing was conducted on AA-1 from October 2010 to September 2011. A total of 25 ballistic tests were completed. During 16 of these tests the aircraft was in a FUSL configuration: engine on, aircraft operating on internal power. Threats in the test program included surface to air warhead fragments, armor piercing projectiles, high explosive projectiles, and a MANPAD.

**Table 1**

System Tested	Number of Tests
Electrical Power System	7
Power and Thermal Management System	4
Flight Control System	8
Vehicle System Network	6
Propulsion	1 (shared with FLCs)

## EPS DESIGN: ROBUST

EPS components are well distributed around the aircraft, providing separation, reducing the effect from larger threats. EPS components are electrically protected as well. Seven shots were conducted across various parts of the EPS system. These tests ranged from simple wiring shots to shots into power conversion and distribution components. The EPS testing was conducted to ensure that damage to one part of the system did not propagate to components upstream of the damaged component, or propagate across redundant paths, ensuring backup power modes were sufficient to provide power for continued safe flight. The 270VDC power generation and distribution system successfully



demonstrated the ability to quickly detect ground faults and isolate damage. The system automatically transitioned to battery fill power, then reconfigured to backup power modes to allow continued safe flight.

## VSN DESIGN: NO CASCADING EFFECTS

VSN architecture successfully detects a damaged component or wire harness and reconfigures to continue communication with other components. Ballistic damage to flight control electronics and wiring was successfully handled by the VSN software error-handling and functional redundancy capability. Due to the nature of the 1394 bus loop, severing a wire or loss of a component resulted in the bus reconfiguring to reestablish communication with the components on either side of the damaged area. Flight control electronic controllers have a further level of redundancy as they pass information on a separate network in the event of bus failures. When components were damaged, the failures seen were benign, with only minor interruption of bus traffic as the bus reconfigured. Ballistic damage to components did not result in the generation of errant signals, the component typically dropped off line. The VMCs flagged the component as failed and reconfigured the bus.

## FCS ARCHITECTURE: NO CHEAP KILLS

One of the newer technologies in the F35 is the Electrohydrostatic Actuators. These actuators contain a self-contained hydraulic system. There are two types of actuators on the aircraft: simplex and dual tandem. The dual actuators have redundancies built in, including dual communication and power paths. The dual actuators were ballistically tested and showed good tolerance to damage. The redundant systems are isolated, and damage on one side did not propagate to the other side.

## FIRE: SIGNIFICANT THREAT

As with most aircraft, fire is the primary vulnerability to the F35. Fire extinguishing is limited to the IPP bay. This system was installed primarily for ground safety reasons. Fuel, hydraulic, and PAO fluids are the primary sources of fire on the aircraft and are distributed throughout the aircraft. As one would expect, fire is a threat to Flight Critical Systems. Ullage protection is provided by an On Board Inert Gas Generating System (OBIGGS). Fuel tank inerting proved successful in this test series preventing fuel tank ullage explosions.



## CONCLUSIONS

The FUSL testing conducted on AA-1 was very successful meeting all defined test objectives and success criteria. Addressing synergistic effects, the electrical power and flight control systems successfully isolated failures and protected the redundancies built into these systems, allowing continued safe flight. The VSN architecture is robust, providing multiple paths to transfer data. Testing highlighted that fire is a significant threat to flight critical systems.

The test team was able to verify that the actual ballistic damage response correlated very well to previous pilot in the loop simulator testing. Over the course of the test program, the LFT team witnessed firsthand the robustness of the F35 flight critical systems, no cheap system kills. [ASJ](#)

# CH-53K LIVE FIRE TEST AND EVALUATION

## The Path Forward

by Marty Krammer

The CH-53K is the next-generation, state-of-the-art, heavy lift rotorcraft platform currently under development for the United States Marine Corps (USMC). As a new acquisition and untested system, the CH-53K will undergo Live Fire Test and Evaluation (LFT&E) to determine its overall vulnerability against threats likely to be encountered in combat. This article discusses aspects of the CH-53K, its requirements, capabilities, survivability features (vulnerability and susceptibility reduction), and the systems engineering approach taken to ensure the CH-53K is the most advanced, effective, and survivable helicopter possible for the war fighter.

The current USMC heavy lift helicopter, the CH-53E, designed in the 1960s and introduced in 1980 as an Engineering Change Proposal (ECP) to the CH-53D, has subsequently developed significant fatigue life, interoperability, maintenance supportability, and performance degradation concerns. The CH-53K is intended to address and satisfy the future needs and requirements of the USMC with improvements in operational capability, interoperability, survivability, reliability, and maintainability while reducing total ownership costs.

The CH-53K heavy lift helicopter is a major systems acquisition managed by NAVAIR PMA-261. The aircraft is being developed by Sikorsky Aircraft Corporation (SAC), is a ground-up re-design that incorporates the latest in helicopter technology, including new General Electric GE38-1B 7,500-hp engines, fly-by-wire flight controls, and composite airframe structures. The advanced capabilities of the drive and rotor systems will enable the aircraft to lift and transport 27,000 pounds over a 110 nautical mile mission range. This combined performance is over two times the capability of a CH-47F and MV-22 and nearly three times the capability of its predecessor the CH-53E.

The CH-53K is a heavy lift helicopter to be employed in the movement of cargo and equipment, the transportation of troops (29 troops plus 3 crewmembers), and for amphibious assault and subsequent operations ashore. The CH-53K improved performance enhancements provide the USMC the heavy-lift payload, speed, endurance, and greater operational reach to support the expeditionary and sustained operations both at ship or ashore.

The CH-53K helicopter will be capable of rapidly embarking aboard and operating from helicopter assault ships and aircraft carriers in support of training, contingency, combat, and non-combat operations. When equipped with approved kits, the helicopter may be



used for vertical on-board delivery of cargo and equipment from ship-to-ship, ship-to-shore, and shore-to-ship. By using attach points in the aircraft and only minimal extra equipment and rigging, the aircraft will be capable of supporting special missions such as casualty evacuation, airborne command and control, rapid ground refueling, forward arming and refueling points, and fast-rope, rappelling, and parachute operations.

## SURVIVABILITY REQUIREMENTS

The CH-53K is designed to be a survivable platform in a combat environment. The survivability requirements for the CH-53K are derived from the Operational Requirements Document (ORD). The ORD identifies seven Key Performance Parameters (KPP), two of which specify the requirements for force protection for the occupants and a level of ballistic tolerance (fly-away-capability given a hit by specified threats). In addition to force protection and ballistic tolerance requirements, the ORD also identifies the need for missile warning and missile jamming or decoying which further enhances the survivability capabilities of the platform. This top level document drives the requirements of the CH-53K Air Vehicle Specification (AVS) where detailed survivability requirements and capabilities (force protection and ballistic tolerance) are specified. These driving requirements ensure a safe and survivable design that exceeds the current capabilities of the CH-53E, while having similar survivability characteristics to the MV-22 rotorcraft.



Figure 1 CH-53K Heavy Lift Helicopter

## SUSCEPTIBILITY REDUCTION FEATURES

Aircraft susceptibility is the inability of an aircraft to avoid being hit by threat systems. Susceptibility reduction for the CH-53K consists of an integrated survivability equipment suite capable of providing threat situational awareness for laser, radar, and missile threats and deploying appropriate countermeasures. Threat situational awareness by the pilots will improve survivability by providing an awareness of the threat environment and making threat avoidance possible.

The Aircraft Survivability Equipment (ASE) suite consists of:

- ▶ Radar Warning Receiver—AN/APR-39B(V)2 (RWR)/Electronic Warfare Management System
- ▶ Directional Infrared Countermeasures System (DIRCM) AN/AAQ-24(V)
- ▶ Missile Warning System (MWS) with laser detection incorporated.
- ▶ Countermeasure Dispenser System (CMDS) AN/ALE-47

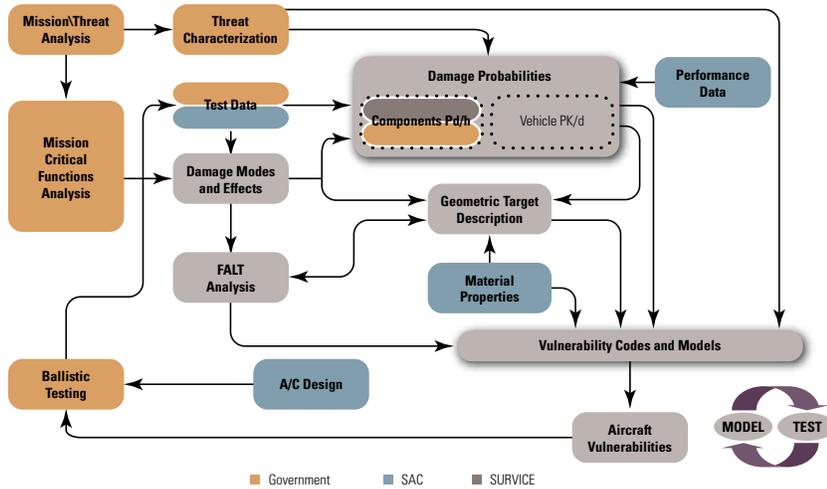
## VULNERABILITY REDUCTION FEATURES

The primary threats of interest, identified within the AVS and ORD include various Anti-Aircraft-Artillery (AAA) rocket-

propelled grenades (RPG) and Man Portable Air Defense Systems (MANPADS).

Vulnerability reduction and force protection design features on the CH-53K (Figure 1) include:

- ▶ **Airframe/Structures**—Composite structure with redundant load paths and reinforcement of structural elements to limit crack propagation
- ▶ **Propulsion**—Three GE38-1B engines (7500-hp class); allowing one engine inoperative (OEI) while maintaining full performance with limited operational capability
- ▶ **Flight Controls**—Double/Triple redundant, separated fly-by-wire control system; increased diameter main rotor pitch rods for greater damage tolerance; ballistically tolerant and jam resistant main rotor and tail rotor servo actuators
- ▶ **Drive System**—Aluminum main rotor gearbox with redundant “dry sump” lube system that reduces oil leak and spray and provides 30 minute operational capability after loss of lube; aluminum intermediate and tail rotor gearboxes with auxiliary lube systems that provide 30 minute operational capability after loss of



**Figure 2** Vulnerability Assessment Process

lube; large diameter tail drive shafts for improved damage tolerance; damage tolerant flex couplings

- ▶ **Fuel System**—Suction feed fuel system with automatic, on-demand fuel boost when required under certain flight conditions; self sealing/crash worthy fuel cell bladders; fuel cross feed redundancy; ballistic tolerant, light weight self-healing cabin fuel line protective sleeves; On-Board Inert Gas Generator System (OBIGGS) for inerting of refuel lines and fuel tanks
- ▶ **Hydraulic System**—Triple redundant hydraulic system with integrated hydraulic isolation systems to reduce the risk of fire and prevent fluid depletion
- ▶ **Rotors**—4th generation composite rotor blade designs with elastomeric bearings for reduced rotor complexity which reduces the number of vulnerable components
- ▶ **Personnel Protection**—Integration of seat and wing armor for the pilot and co-pilot along with cabin floor and wall armor for passenger protection; crash resistant seats for both cockpit and cabin occupants

The CH-53K’s survivability reduction features will be evaluated and verified either through ground tests, flight tests, analysis efforts, or LFT&E.

## VULNERABILITY ASSESSMENT PROCESS

The ORD survivability and force protection KPPs established the requirements in the AVS for a maximum vulnerability and a required level of personnel protection for the pilots and cabin occupants. The analysis process to evaluate these requirements utilizes the Ballistic Research Lab Computer Aided Design (BRL-CAD) geometry modeling tool and the Computation of Vulnerable Areas Tool (COVART) along with the process

detailed in Figure 2. The result of this process is the vulnerability assessment of the CH-53K. The survivability team reviews these results to verify AVS compliance and to identify areas where vulnerability reduction features may be integrated and where ballistic risk reduction tests could be conducted to support refinement of the ballistic vulnerability. One example of this review process was the identification of the tail rotor driveshaft and the tail rotor flexbeam for risk reduction tests to better understand the vulnerability of these components. The positive result from these tests was then integrated into the assessment. The progression of the analysis results displayed in Figure 3 highlights the integration of these test results and several other refinements into the vulnerability assessment.

The vulnerability assessment of the CH-53K is a continuous process conducted and continually monitored to evaluate system, subsystem, and component vulnerabilities integrating methodology refinements and live fire test data to ensure the platform meets the AVS requirements.



**Figure 3** CH-53K Vulnerability Analysis Progression

## LIVE FIRE LAW REQUIREMENTS

The CH-53K is a new and untested major acquisition program (No. 390) and has been designated as a covered system under US Code Title 10, Section 2366 (10USC2366). The code stipulates that realistic survivability LFT&E be conducted on a fully operational, combat configured system prior to proceeding beyond the low rate initial production (LRIP) milestone. LFT&E will support the vulnerability assessment in identifying the CH-53K helicopter vulnerability against ballistic threats, which are likely to be encountered in a combat environment, providing crucial insight into the performance during complex ballistic events (e.g., fire initiation, and propagation, dynamic performance of damaged components and systems, and effects on occupants).

In June 2005, prior to the Milestone B acquisition timeline, the CH-53K program office (PMA-261) submitted the CH-53K Alternate LFT&E strategy, appendix to the CH-53K Test and Evaluation Master

Plan (TEMP), to the office of Director, Operational Test & Evaluation (DOT&E) and obtained a waiver from full-up system-level (FUSL) LFT&E on the grounds that it would be prohibitively expensive and unpractical. The approved strategy provided a detailed approach for determining vulnerability, including the testing of components, sub-system articles and developmental test assets; performing analysis through modeling and simulation; and utilization of existing combat and live fire test data from similar systems.

The CH-53K Alternate LFT&E strategy has been updated since 2005 as a result of aircraft design maturation, the most recent being Revision C, approved 21 June 2010. Vulnerability assessments and trade studies conducted at significant design milestones supported updates to the Alternate LFT&E strategy and ensured the strategy was in-line with meeting the AVS, KPPs, and LFT&E requirements. The critical components identified within the Alternate LFT&E strategy will be assessed in a series of ballistic tests, with the results being

integrated using modeling and simulation to obtain a complete system-level vulnerability assessment at the end of program.

## CH-53K LIVE FIRE TESTING

Key focus areas for the CH-53K LFT&E program are to:

- ▶ Capture collateral and cascading effects during ballistic events
- ▶ Assess potential crew and passenger casualty
- ▶ Assess CH-53K battle damage assessment and repair procedures
- ▶ Provide vulnerability comparison of the CH-53K with the legacy CH-53E
- ▶ Identify modifications which can reduce the vulnerability of the CH-53K
- ▶ Assess the ballistic tolerance for every component and subsystem considered critical to flight

The CH-53K Alternate LFT&E strategy outlines a system engineering approach to testing, initially conducting component-level testing for the purpose of limiting program risk, then transitioning to aircraft representative, full-up operational system-level testing to provide critical data for obtaining a complete and thorough vulnerability assessment of the aircraft.

Component-level tests involve ballistically evaluating critical components (identified from analysis) using either stand-alone, static load capable test fixtures, or when practical, sub-system, spin (dynamic) capable test stands designed to operate components under representative flight spectrum load conditions. All damaged components are then further endurance tested for an additional 30 minutes of operation, demonstrating a return to a safe zone capability. Components tested using the

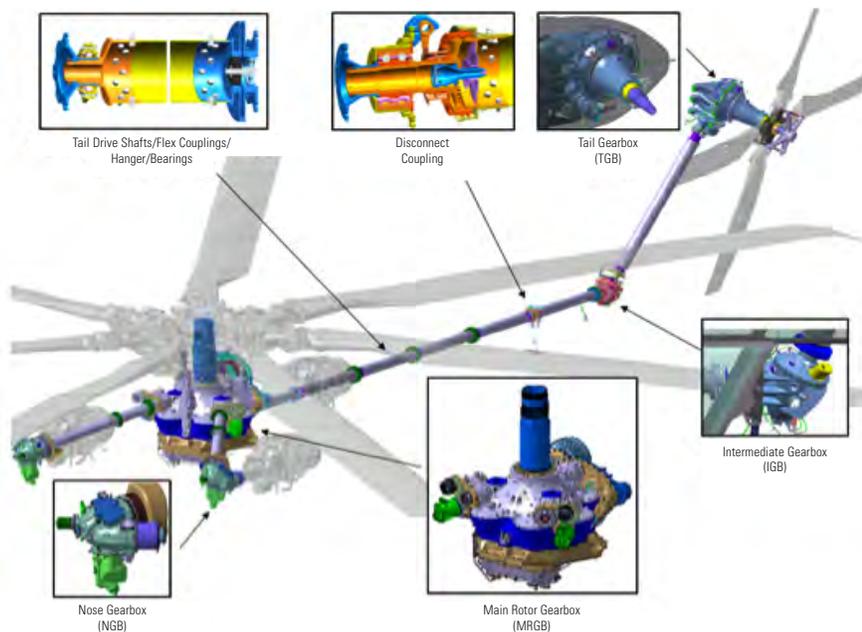


Figure 4 CH-53K Drive System



Figure 5 Tail Rotor System



Figure 6 MR Assembly – (Swashplate, Pitch Control Rods, Scissors)



Figure 7 MR & TR Servo Actuators



Figure 8 GE38-1B Turboshaft Engine

stand-alone, static test fixtures are slated to be endurance tested at SAC with fatigue, cycle-type, test equipment. Components evaluated using the dynamic test stands will be endurance tested immediately post impact.

Component-level testing will address the component vulnerability of the:

- ▶ **Main and Tail Drive System (Figure 4)**—drive shafts, bearings, flexible diaphragm and disconnect couplings, and all gearboxes (MRGB, IGB, TGB)

- ▶ **Tail Rotor System (Figure 5)**—blades, pitch change shaft, hub, beam, and pitch control links
- ▶ **Main Rotor System (Figure 6)**—blades, hub, pitch control rod, sleeve, yoke, cuff, shaft, swashplate, and stationary scissor
- ▶ **Flight Control Components (Figure 7)**—main and tail rotor servos (ballistic tolerance, jam potential, and break away capability)
- ▶ **Propulsion System (Figure 8)**—GE38-1B engine, 7500-hp class (disk burst – cascading damage)

System-level testing will address the aircraft and crews response to collateral and cascading damage effects from ballistic impacts to the:

- ▶ **Main and Tail Drive System**—shafts, bearings, flexible diaphragm and disconnect couplings, and all gearboxes (MRGB, IGB, TGB, NGB)
- ▶ **TR Rotor System**—blades, pitch change shaft, pitch horn, pitch beam, and control links
- ▶ **Main Rotor System**—blades, sleeve, cuff, yoke, hub, spindle and swashplate
- ▶ **Fuel & Hydraulic Systems**—refuel, defuel, and feed fuel lines; sponson structure, dry bays, fuel cells; primary and utility hydraulic system; OBIGGS purge and inerting
- ▶ **Engine Bay Fire Protection System**—sensors and extinguishing systems
- ▶ **Flight Control System**—flight control computers and wire harnesses, MR and TR servos
- ▶ **Force Protection Systems**—cockpit and cabin armor
- ▶ **Structure**—primary frames, transition folds, and tail structure

System-level tests will involve the use of a fully operational, remote controlled CH-53K Ground Test Vehicle (GTV) capable of achieving in-ground hover



Figure 9 CH-53E Hover Stand

during test. The test data gathered will contribute towards verifying vulnerability ORD and AVS requirements and provide a complete vulnerability assessment, which identifies the aircraft's capabilities and limitations for threats likely to be encountered in combat. Figure 9 provides an example of a system-level, full scale remote controlled vehicle (the CH-53E) mounted on the floating hover stand during the Joint Live Fire test program conducted in May of 2006.

For budgetary purpose, the LFT&E program was split into two phases. Phase-I testing (2013–2018) being associated with the current System-Design-Development (SDD) contract, addresses all threshold threats defined in the CH53K ORD and AVS. Successful completion of the Phase-I test series (Table 1) will satisfy the Title 10 LFT&E requirements for completion prior to the beyond LRIP decision point milestone. The threshold threats are what the CH-53K is designed to. This is the minimum capability the USMC has asked for within the ORD.

Phase-II testing (Table 2) is identified as a Follow-On-Test-and-Evaluation (FOT&E) program effort and is listed in the CH-53K TEMP and capabilities roadmap accordingly. Phase-II testing (2019–2021) will address the more challenging objective threats as described in the ORD and AVS for the purpose of gaining additional insight into additional system capabilities against more challenging threats to be encountered in combat.

**Table 1** Phase-I Live Fire Tests

Phase-I Component-Level Tests	Year
MR Pitch Control Rod	2013
Stationary Scissors	2013
Swashplate	2013
TR Beam & Control Links	2013
TR Blade	2014
Tail Drive System (Shaft, Coupling, Disconnect, Bearing)	2014
Tail & Intermediate Gearboxes	2014
Main Rotor Gearbox	2014
GE38 Rotor Components	2013
GE38 Ballistic Vulnerability	2014
Phase-I System-Level Tests (GTV)	Year
Tail Drive & TR Flight Controls	2017
Fuel Feed-Refuel, -Dump systems, hydraulics, engine bay	2017
Main Rotor Flight Controls (MR & TR Servos, FCCs), Structure, Armor	2018

**Table 2** Phase-II Live Fire Tests

Phase-II Component-Level Tests	Year
MR Shaft	2019
MR Blade	2019
MR Hub	2019
MR Yoke, Sleeve, Cuff	2019
TR Hub	2019
Phase-II System-Level Tests (GTV)	Year
Tail Drive & TR Flight Controls	2020
Fuel, Hydraulics	2020
Main Rotor Flight Controls	2020

Ballistic threats and shot line determination are selected by taking into account component and system criticalities, simulated combat scenarios, likelihood of being hit, damage and system response uncertainties, and filling data voids. Threats that are assessed as over-matching for the CH-53K will not be tested and will be addressed through analysis or similarity.

The US Naval Air Warfare Center Weapons Division, Weapons Survivability Laboratory, China Lake, CA, is the test agency identified to support LFT&E of the

CH-53K. The facilities are fully equipped and staffed to support (plan, conduct, instrument, load, operate, record, and report) LFT&E needs.

The CH-53K survivability team reports all planning and test activities to the program manager PMA-261. The survivability LFT&E team consists of the Naval Air System Command (NAVAIR – China Lake and Patuxent River), Sikorsky Aircraft Corporation (SAC), SURVICE Engineering Company (SURVICE), Director

of Operational Test and Evaluation (DOT&E), and the Institute for Defense Analysis (IDA).

## SUMMARY

The CH-53K is the US Marine Corps' next generation heavy lift platform that includes the latest in helicopter technology to provide the war fighter a more capable and survivable platform than its predecessor the CH-53E.

The CH-53K Alternate LFT&E program is structured to determine the aircrafts ballistic tolerance against threats likely to be encountered in battle. The program will provide a complete assessment capability on the aircraft design, verifying the vulnerability ORD and AVS requirements. Test data and lessons learned from the CH-53K LFT&E will further assist in identifying critical component and subsystem vulnerabilities and will aid in developing solutions to improving survivability and making the CH-53K the least vulnerable military helicopter. [ASJ](#)

# EXCELLENCE IN SURVIVABILITY

## MARTIN N. KRAMMER

by Joseph Manchor

The Joint Aircraft Survivability Program takes pleasure in recognizing Mr. Martin N. Kramer for Excellence in Survivability. "Marty" is a project engineer with the Combat Survivability Division of the Naval Air Systems Command (NAVAIR), located at China Lake, CA. Marty is currently the lead for the CH-53K Live Fire Test and Evaluation (LFT&E) Program. However, his previous experience as the Lead Range Engineer for the Weapons Survivability Laboratory (WSL) is particularly noteworthy, as he was instrumental in the design of multiple new test capabilities that vastly improved the realism and fidelity of LFT&E. Throughout his career, he has provided support through the design and development of advanced test fixtures for nearly every LFT&E program conducted to date at the WSL, including A-12, P-7, F/A-18E/F, V-22, AH-1Z, UH-1Y, MH-60R/S, and F-35.



Marty started his career soon after graduation from high school working for the Department of Corrections at Folsom Prison,

where he spent two years teaching drafting techniques to prison inmates. Marty received his BS in mechanical engineering from the University of California in 1989 and was subsequently hired to support the WSL at China Lake as a Range Engineer. In this position, he was responsible for the design and fabrication of unique test fixtures that are needed to support live fire testing. One of Marty's first assignments was assisting in the design and

implementation of the upgrade for the WSL's High Velocity Airflow System (HIVAS), completed in 1992. This massive fixture was improved from its previous two-engine capability to provide four-engine airflow to better simulate in-flight airflow conditions for fixed wing aircraft undergoing ballistic live fire testing.

In 1995, Marty was tasked to support the Joint Live Fire (JLF) program through the development of a method to conduct remote-controlled hover flight of helicopters undergoing ballistic testing. This effort resulted in the development, design, and fabrication of special hover fixtures that allow test helicopters to safely achieve hover flight while minimizing the potential for entering hazardous ground resonance condition. These specialized fixtures also restrict horizontal movement of the hovering helicopter preventing it from wandering from its test pad, thus allowing for the accurate aiming of components on the test helicopter. This method of testing has subsequently become adopted as the standard for helicopter live fire

testing and has been repeatedly used for testing under the MH-60R/S and UH-60M LFT&E programs, the CH-53E JLF test program, as well as Hostile Fire Indicator (HFI) testing. It's also currently planned for testing under the CH-53K LFT&E program.

Marty was also one of the first to propose the launching of MANPADS missiles for ballistic testing through the use of an airgun. In 1995, under JLF sponsorship, Marty designed and had fabricated what subsequently became known as the Missile Engagement Threat Simulator (METS) Gun. This huge 40-foot airgun is capable of projecting a MANPADS missile at expected missile/aircraft encounter velocities. It also allows for extremely accurate impact of these missiles, providing needed data for validation of MANPADS vulnerability models. The METS gun has also become the standard for evaluating MANPADS vulnerability and has been used for multiple JLF and LFT&E program tests.



Figure 1 HIVAS



**Figure 2** Helicopter Hover Fixture at HFI Facility

In 2004, Marty received his MS in mechanical engineering from the University of California. The same year, he also decided to pursue new opportunities away from the Mojave Desert and outside of the Department of Defense. Marty moved to Minnesota in 2004 where he worked as a senior design engineer developing power trains for motorsport vehicles. While there, he was awarded Patent No. US 7,367,913 B2 for the invention of a new wet brake system for vehicles. But the call of the desert never left Marty, and he eventually returned to the China Lake Combat Survivability Division as a Test/Project Engineer in 2006.

In 2007, the WSL was tasked to construct a new test facility to support a projected increase in testing requirements. This new facility would have vastly improved airflow capability over the current HIVAS system, allowing improved support for expected aircraft programs such as the Joint Strike Fighter. Due to Marty's previous work in the development of the four-engine HIVAS airflow, he was assigned the development of this airflow system for this new test site. Marty designed and oversaw the fabrication of what



**Figure 3** Missile Engagement Threat Simulator (METS) Gun



**Figure 5** Super HIVAS

subsequently become known as the Super High Velocity Airflow System (Super HIVAS). This nine-turbofan engine behemoth is capable of providing airflow in excess of 500 knots over an area of 38 sq ft. It has proven very effective in testing, and has been used for fixed wing LFT&E and JLF testing since becoming operational in 2010.

Marty's latest endeavors have focused on the coordination and execution of the CH-53K LFT&E program. He has performed admirably as the lead for this test program, as he oversees technical efforts for planning of the CH-53K Alternate Live Fire Test and Evaluation Strategy. Through Marty's efforts, the program strategy relies on the increased use of dynamic testing over static test methodology, thus ensuring realism and fidelity of test results. Marty's participation and input at numerous design reviews has also led to several design changes that improve the survivability of the CH-53K aircraft. Marty is also a key member of the CH-53K Survivability Engineering Team and has conducted several early risk reduction type live fire tests to validate the vulnerability model allowing the CH-53K to meet its very important Survivability Key Performance Parameter (KPP).

Away from work, Marty enjoys spending time with family, outdoor activities, hiking, skiing, golf, tennis, fly-fishing and water activities, and also attending sporting events.

It is with great pleasure that the Joint Aircraft Survivability Program (JASP) honors Marty Krammer for his Excellence in Survivability contributions to the technical community, the JASPO, the Survivability discipline, and the warfighter. **ASJ**

# LIVE FIRE TESTING A LEGACY WING

## Assessing Dry Bay Fire Potential in the C-5 Wing

by John S. Kemp and Lisa H. Woods

The C-5 has been subjected to a much needed modernization program in the last decade. One phase of this modernization was the Reliability Enhancement and Re-engining Program (RERP). Because of this modernization, it was determined by the Office of the Secretary of Defense (OSD) that the C-5M aircraft was a covered system for Live Fire Test and Evaluation (LFT&E). One of the areas of interest was vulnerability to dry bay fires for the C-5 legacy wings. The C-5 RERP LFT&E program addressed these questions.

The C-5 legacy wing was subjected to live fire testing as part of the overall C-5 RERP LFT&E program. As a result of past lightning strikes and fires, an inerting system was added to protect the wing fuel tanks. The inerting system, called the Fire Suppression System (FSS), was plumbed to the leading edge dry bays of both wings, in addition to inerting the fuel tanks. This added FSS was never evaluated or tested to see if it would prevent or extinguish dry bay fires in the C-5 wings. The primary objectives of the current testing effort were to determine the ignition and sustained fire potential in wing dry bays, both leading and trailing edges, and assess the FSS in preventing or extinguishing potential fires. The secondary objectives were to determine the damage of pressurized hydraulic lines within the wing and assess the extent of damage on the hydraulic systems. Five ballistic shots were performed on this unique, large wing. Three shots were performed on the leading edge and two ballistic shots were accomplished on the trailing edge to collect data for the primary and secondary objectives. The test article selected was a left hand wing section that contained the #1 Auxiliary Fuel Tank and the #1 Main Fuel Tank. This

is approximately the outboard half of the overall wing, past the outboard engine pylon. Pre-tests were accomplished to assess and evaluate how long the FSS takes to get below 12% oxygen in the leading edge and how airflow travels through the dry bay of the legacy wing. This information allowed better pre-test setup and for the main ballistic testing and better conclusions. Simulated airflow, from engine bypass air, was blown over the test article at approximately 250 knots to better simulate airflow and flight conditions. The five shots on the C-5 legacy wing test article resulted in two sustained fires and one self-extinguishing fire. The damage, due to both ballistics and fire, was repaired after each test event to preserve the integrity of the legacy wing for each following test. The data provides insight to the ignition and fire potential of combat threats that impacted the C-5 legacy wing during testing. This provided valuable information to the war fighter, making them more informed and allowing for more informed decisions. This effort also exhibited the value of risk reduction pre-tests performed prior to the live fire test events and that such activities were critical to reaching the end goals of live fire testing.

## INTRODUCTION

The C-5 has followed through with a needed modernization program. There were multiple phases of this modernization and one was the RERP. Because of this modernization, it was determined by OSD/ Director, Operational Test and Evaluation (DOT&E) that the C-5M aircraft was a covered system for (LFT&E) under Title 10, United States Code Section 2366. A waiver from Full-up System Level (FUSL) testing was requested, accompanied by an alternative live fire test and evaluation test plan (ATP). Under Secretary of Defense for Acquisition, Technology, and Logistics (USD AT&L) approved the waiver request on 2 November 2001. The ATP identified potential LFT&E areas of interest for the C-5M aircraft. One of the areas of interest is vulnerability to dry bay fires. The wing for the newly designated C-5M aircraft is the same as the wing on earlier versions of the C-5 aircraft. Given the wing had not been tested before, in this capacity, an investigation was necessary to determine if they were vulnerable to dry bay fire. Also, the wing includes a liquid nitrogen FSS onboard the C-5M. It is used to protect and pressurize the fuel



**Figure 1** Wing Integral Fuel Tanks

tanks by inerting the fuel ullage space. The FSS was also configured to provide fire suppression capability in the “unmanned zones” of the wing leading edge. The FSS is plumbed into these zones or spaces around the fuel tanks; Figure 1 shows the layout of these fuel tanks. These unmanned zones are dry bays in front of and behind the main spars in the wing. To address the C-5M aircraft’s potential vulnerability to dry bay fires and adequacy of the current firefighting system, ballistic data on the

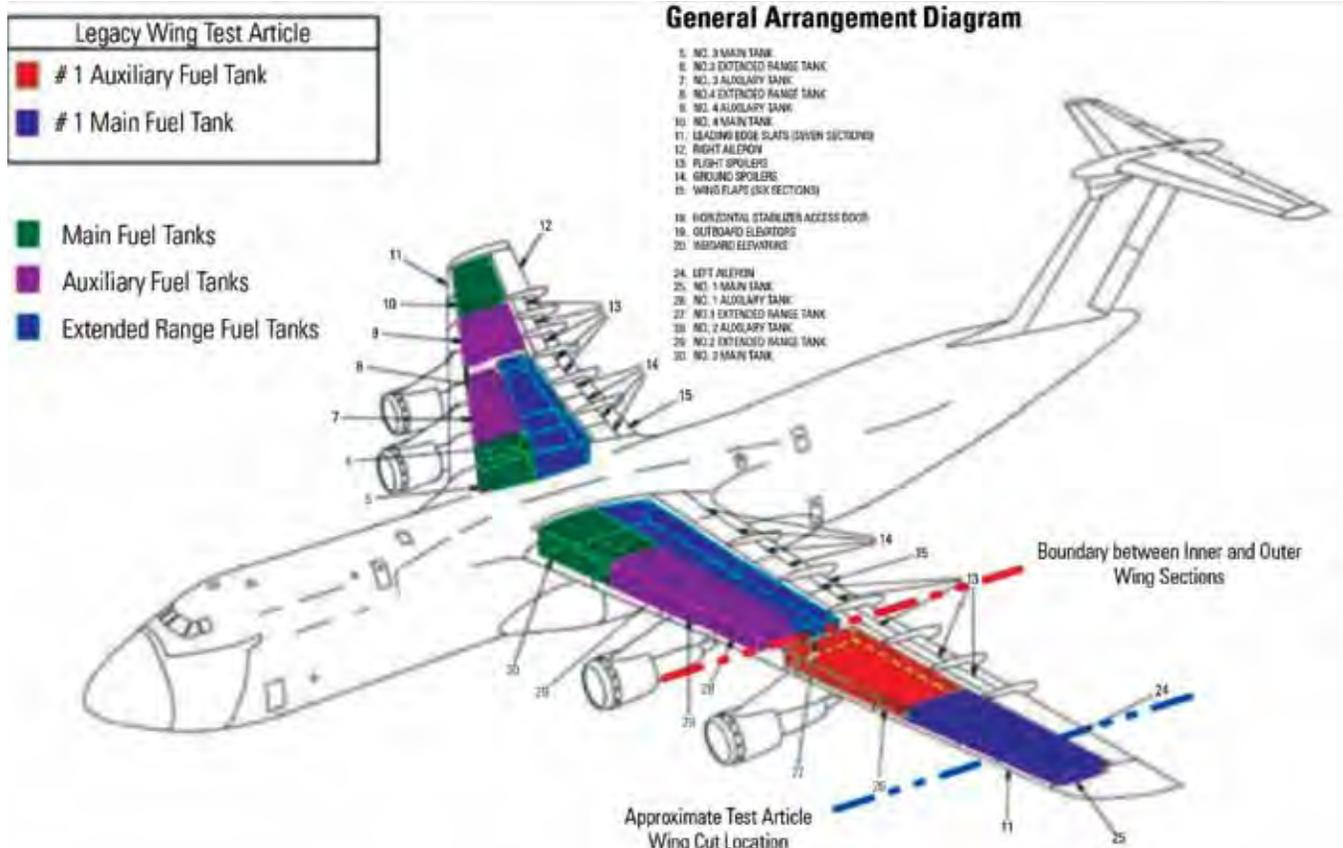
effects of projectile penetration into the main dry bays of the C-5M aircraft and fire ignition data were generated and analyzed.

There were several objectives associated with legacy wing testing. The primary objective was to determine the probability of fire associated with the leading and trailing edge dry bays due to ballistic impact. The secondary objective was to evaluate the FSS, which was only plumbed into the leading edge of the wings. Since the C-5 legacy wing had never been evaluated through LFT&E, a tertiary objective was to evaluate the ballistic damage and associated battle damage repairs required after each test. In order to meet these objectives, the capture of large quantities of data was required. Figure 2 shows the planned wing section that will be the test article, between the red and blue lines, both regular and high speed provided

visual evidence of fire ignition and sustainment. Thermocouples provided a profile of temperature increases within dry bays.

## APPROACH

The test article was an outboard, left-hand, C-5 wing section. The test article was obtained from the 309 Aerospace Maintenance and Regeneration Group (309 AMARG) at Davis-Monthan AFB in Arizona. Permission was obtained to use a retired C-5 asset from which the test article was acquired. The outboard wing section was cut from the C-5 asset and shipped to the 46th Test Group. This outer wing section (between WS 777.275 and WS 1238.728 (OBWS 2000.000 – OBWS 575.308) contained hydraulic lines, electrical wires and bundles, a bleed-air duct, spars, ribs, slats, flaps, and fuel tanks (#1 Auxiliary and #1 Main). Supplying the LFT&E



**Figure 2** Fuel Tank Layout in Legacy Wings



**Figure 3** C-5 Left Hand Legacy Wing

program with a new production wing to test would have jeopardized the overall LFT&E schedule and been very costly. Not to mention, there are no new production wings available. Re-using a costly test article, for what amounts to a destructive test, is the best option from a fiscal and schedule standpoint for accomplishing live fire testing. Figure 3 shows the legacy wing test article as received from AMARG.

The shot matrix for testing planned 6 shots on the legacy wing and it was decided that an outboard section was large and long enough to support those 6 shots. The legacy wing contained production structure and lines in the leading edge. The leading edge slats were obtained and added to the article as well as the trailing edge flaps. These items were needed to correctly direct the airflow over the test article at 230 knots over the leading edge and 150 knots over the trailing edge, to better simulate necessary flight conditions. Figure 4 shows the final product of the modifications and additions for the legacy wing test article in the 46th Test Group Aerospace Vehicle Survivability Facility (AVSF) at Wright-Patterson AFB Ohio, range 3. The figure shows the wing



**Figure 4** C-5 Legacy Wing in AVSF Range 3

sitting in front of the airflow duct with various support equipment surrounding the wing.

While the lines, low and high hydraulic pressure, electrical, FSS, and bleed air, were maintained in the leading and trailing edge, the test did have to supply accurate pressures and supplies for these lines. Internally, the legacy wing was populated with hydraulic, electrical, environmental (bleed-air), and other items designed to represent and operate at the proper conditions (temperature, pressure, flow rate) to recreate an operational C-5M aircraft. Figure 5 shows the larger bleed air duct, which is the lower line in the figure. Above the larger bleed air duct is the FSS line. Above the FSS line, at the top, are the two, low and high, hydraulic pressure lines. In addition to the spar and fuel tank being a target, the hydraulic lines were also a target during the first shot. All of these lines sit in front of the spar in the leading edge dry bay.

The fuel tanks in the C-5 hold over a thousand gallons of fuel. To reduce this amount, somewhat, air filled bladders were added to the fuel tanks to bring the overall fuel gallons, during a test, to 1400 gallons. Figure 6 shows the trailing edge spar along with accurate clutter in the dry bay. The target was the rear spar and the fuel behind it. Again, the C-5M representative parts were left installed in the legacy wing to provide operational



**Figure 5** C-5 Legacy Wing Leading Edge Dry Bay

accuracy. There were no planned shots, on hydraulic lines, to check the fire ignition probability in the trailing edge.

The last test in the shot matrix was at a spar location where three hydraulic lines run together, within the fuel tank. The shot determined if a single round could incapacitate all three hydraulic lines at one time. The hydraulic lines were missing from the test article. Hydraulic lines were added, in the fuel tank, with representative parts. These representative parts were similar in outer diameter, wall thickness, and internal pressure to the real lines, not part of the original wing shipment.

Due to testing results, the last shot needed to be accomplished in range two. Airflow was not needed for the last shot, so moving to range 2 was considered acceptable. While the other tests used JP-8 fuel, this last shot did not require fuel in the tanks. Water is considered a good replacement when the intent is not to ignite a fire during testing. The specific gravity of water and fuel are comparable, though not exactly the same.

The surrogate right hand wing, with attached water reservoir, is shown in range two in Figure 7. The stands shown in the picture above were necessary to orient the wing at the proper angle of attack and hold the article up off the ground.



**Figure 6** C-5 Legacy Wing Trailing Edge Dry Bay



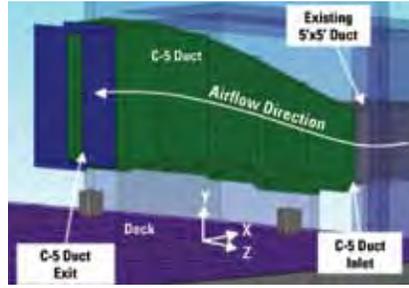
**Figure 7** Surrogate Right Hand Wing with Water Reservoir

Test execution involved airflow blown over the legacy wing test article. The goal is to create flight conditions which are as realistic as possible, without leaving the ground. The airflow test facility is shown in Figure 8. The bank of five engines, producing the bypass air, is off to the right in the figure. The bypass air is then placed into a main nozzle system, shown in the center of the Figure 8.



**Figure 8** 46<sup>th</sup> Test Group Airflow Test Facility

While the AVSF range 3 facility is capable of producing airflow at 400 knots, the legacy wing test only required 230 knots of airflow over the leading edge and 150 knots over the trailing edge. Five engines produce bypass air which is channeled into a main duct, producing the airflow for the test range and the test article. While not a wind tunnel facility, the system does a good job of providing relatively clean airflow over the test article, for simulated flight conditions. A custom airflow duct was designed to reduce the turbulence percent, eliminate any dominant frequencies, and improve the speed of the airflow by the time it reached the test article. This customized duct attaches to the end of the main duct system, which is at the start of AVSF range 3 proper. Any customized duct can



**Figure 9** Custom Airflow Duct

be attached to the main bypass air duct to give a test of its own type and variety of airflow and speed.

The custom manufactured duct is shown in Figure 9. The airflow duct is the bridge between the bypass air from the engines and test article. It is the one opportunity to improve the air quality before it reaches the test article, creating more flight realistic airflow. The limitation for airflow is wetted area. The wetted area for the legacy wing test is the width of the duct, which was about five feet. The flying legacy wing has airflow over the entire wing and not just a section of wing. A pre-test was needed to determine the airflow speed and direction within the legacy wing while airflow was being blown over just a section of the test article.

Pre-tests are accomplished to reduce the risk during regular testing and to the overall program. Pretests also determine needed test variables and settings which required more than research to determine. Two pretests were accomplished before legacy wing testing started. The first was a Helium Bubble Airflow Quantification in the leading edge dry bay of the legacy wing. The goal was to get a feel for how fluid flowed in the leading edge dry bay and highlight any possible changes to garner the proper mass flow rate and direction. A dry bay simulator was constructed to get basic measurements and camera calibrations. Figure 10 shows helium bubbles traveling through the dry bay.

The helium bubbles were photographed on a high speed digital camera. These images were mapped using an updated piece of software. The output of this software is speed and direction or velocity vectors for the flow fields. The result of the pre-test was to add a ducted fan at the end of the legacy wing test article. This provided an increase in mass flow rate within the test article and better simulated the airflow environment.

Nitrogen for the fire suppression system is driven by the self-generated pressure in the dewars through two master fire valves to the 12 zone valves distributed throughout the aircraft. The zone valves control the nitrogen routed to a number of spray nozzles located so that each fire suppression zone can be thoroughly saturated with nitrogen when its associated zone discharge pushbutton is depressed. The second pretest was needed to check the time at which the oxygen percent fell below 9%. When the legacy wing test article was placed in the test range and instrumented, a pressure vessel of nitrogen was used to simulate the dewar in the fuselage. The correct line length was used between the source of nitrogen and the test article to get the nitrogen travel time accurately. The time to reduce the legacy wing dry bay to 9% oxygen was determined. This time was then used to offset the inerting time for the dry bays during testing. The potential fires were allowed to burn for 10 seconds in order to justify a sustained fire. Ten seconds into testing, after the shot, the



**Figure 10** Helium Bubble Flow Field within the Simulator

nitrogen was in the dry bay was being inerted. By shortening the time to inert the dry bay, during testing, the FSS system was given every opportunity to put a fire out.

The pretests were important because the two problems had the potential to invalidate the final data, in their own way, either by a mismatch in the timing of the nitrogen release or mis-characterizing the general fluid flow properties within the dry bay.

Data acquisition was accomplished through LabView v8.2.1. The data gathered during testing were thermocouple data (Type K), pressure transducer data, flash detector information, high speed video inside the legacy wing, and normal speed video inside and out of the leading and trailing edge dry bays. The gathered data was able to show where a fire was located within the legacy wing dry bays. The thermocouple data illustrated how long the fire lasted and the temperature of the fire, up to about 2000 deg. F. There were 11 thermocouples in the leading edge of the wing and 11 in the trailing edge of the wing. The pressure transducer data was showing the pressure within the lines of flammable fluids. If the projectile severed a line, the pressure transducers would indicate a fluid loss in the line by a decrease in the pressure reading. The temperature and pressure data within the legacy wing was taken at a rate of 4000 Hertz. Table 1 shows a breakdown of the instrumentation in each leading and trailing edge dry bay.

The total instrumentation package was designed to track projectile incendiary functioning, fire ignition, sustained and self-extinguishing fires, and general nitrogen flow all within the dry bays.

**Table 1** General Instrumentation used for both Leading and Trailing Edges

Thermocouples	LE/TE
Type K (0-2000°F) Each Spar Web / Fuel Tank Wall	6
Type K (0-2000°F) Bleed-Air Duct	2
Type K (0-2000°F) Each Hydraulic Reservoir	1
Type K (0-2000°F) Inside Fuel Tank	2
Pressure Transducers	LE/TE
Kistler Strain Gages (0-5000 psig) – Affixed to a rod for moving to bay being tested	4
Sensotech Strain Gage on spars	8
Based Pressure Transducers Each Dry Bay	4
O2 Sensors	LE/TE
Oxygen Sensors	2

## RESULTS

The results section presented here is an overview or summary of typical test results. While the detailed results in the test report would have dozens of pictures and instrumentation traces and plots, the results here will give samples of the type of data acquired and damage resulting from the ballistic threats.

Table 2 is a summary table for the legacy wing testing. It contains test conditions and results for the C-5 LFT&E, legacy wing test.

An explanation of the table is necessary to further understand the results as presented. There were eight test events total on the C-5 legacy wing. In the event column, if there is a “B” next to the event number, then it is a repeated shot because of a minor change made to the original event in the test matrix. To maintain the integrity of data gathered, a repeated shot was necessary to validate results with the minor test event changes. The threat column shows no listed threats used during testing. The test was looking to see how different threats effected damage and fire initiation. For purposes of security classification, the specifics of the threat are not discussed or mentioned in the paper. What can be said is that different types of threats

were used in the current test effort. The azimuth refers to the horizontal angle of the gun used in testing. An azimuth of zero or 360 degrees is pointed at the imaginary nose of the aircraft. The elevation indicates the vertical angle of the gun used for the individual tests. For example, an elevation of 0 degrees means the gun barrel is horizontal, while a 90 degree elevation has the barrel pointing straight up. A number of things dictate the final azimuth and elevation of the gun barrel. Final range setup and layout was one of those factors that determined the orientation of the gun. The manner in which the projectile enters the target plays a role in the type and amount of damage experienced during a test. It also has an influence over fire initiation. The speed of the projectile indicates the muzzle speed as the projectile leaves the barrel. Because of the proximity of the gun to the target, the muzzle speed is considered the target impact speed. It is important to note, the gun was far enough away from the target to remove any muzzle blast effect on the target itself. The impact speed needs to be more representative of a realistic combat event. Instead of striking the target at service speed, which is very high, the rounds were downloaded to slow them upon target impact. This slower speed simulates a modest amount

**Table 2** Conditions and Fire Results Table from Legacy Wing Testing

Summary Results Table												
Test Event	Threat	Azimuth (deg.)	Elevation (deg.)	Threat Speed (ft/s)	Slats/Flaps	Air-flow (knots)	Fuel Level %	Target Bay	Target	Temperatures (deg. F)	Fire Type	Fire Duration (sec.)
1	–	0	85	1910	Retracted	250	0	Leading Edge	Hydraulic Return Line	Ambient	None	N/A
1B	–	0	85	1876	Retracted	272	0	Leading Edge	Hydraulic Return Line	Ambient	None	N/A
2	–	0	17	2176	Retracted	275	100	Leading Edge	Front Spar Web	>100	Sustained	+17
3	–	0	20	1853	Retracted	161	100	Leading Edge	Front Spar Web	980	Self Exstinguishing	+14
4	–	0	35	1542	Retracted	184.5	100	Trailing Edge	Rear Spar Web	Ambient	None	N/A
4B	–	0	28	2013	Retracted	181	100	Trailing Edge	Rear Spar Web	>1800	Sustained	+15
6	–	0	30.4	1990	Retracted	None	100 (water)	Trailing Edge	Multiple Hydraulic Lines	N/A	N/A	N/A
6B	–	0	44.9	2126	Retracted	None	100 (water)	Trailing Edge	Multiple Hydraulic Lines	N/A	N/A	N/A

of deceleration experienced by the projectile on its way to a real target, at both altitude and distance. The slats and flaps were a way to vary the airflow around the test article at the leading edge and trailing edge of the legacy wing. The slats and flaps on the test article had two positions, either retracted or extended. The test was designed to examine if slats and flaps had an effect on fire initiation, because of the different types of circulation produced around the leading edge and trailing edge of the legacy wing. External airflow was blown over and around the test article between approximately 150 or 250 knots, to better simulate different flight conditions. Again, the test was constructed to determine if external airflow played a role in fire initiation. As mentioned before, there were two target bays on the legacy wing. The leading edge dry bays were in front of wing and the trailing edge dry bays were behind. When testing in these dry bays, the shots would impact the bays in

a low, high, or at mid-level mode. By targeting the dry bays in this way, the results would show if there is any particular position or location that produces more damage and was more likely to initiate a fire. The ultimate target was the spars and hydraulic lines in the legacy wing. There were different hydraulic lines and a bleed air line, all under realistic, test pressures and temperatures. The hydraulic lines targeted were the high and low pressure lines routed in front of the spar. One shot was accomplished on a pressurized hydraulic supply line holding hydraulic fluid. The pressures within the different lines varied, and modeled what is in the real C-5 aircraft. They were as low as 80 psi and as high as 2,762 psi, depending on the line in question. There were three types of fire events recorded during testing. A “sustained” fire would not go out by itself and required external fire extinguishing to stop. Also, a “sustained” fire was defined if it lasted longer than 10

seconds immediately after the shot, without significantly decreasing in size or again going out on its own. A “self-extinguishing” fire goes out on its own prior to the 10 second time increment. It was also possible for “no fire” to ignite during the testing. The final column in the results table shows the duration of the fire. Assuming external fire extinguishing, test range CO2, around the test article is unchanged from shot to shot and a constant, the longer duration fires are considered to be more robust than the shorter duration fires.

It can be seen from Table 2, that the eight shots in the matrix are a combination of 5 original test events and 3 repeated tests. The main factor in repeating a shot was projectile functioning. The last test event, number 6, was not a fire initiation test. The rest of the test events, 1 through 4, were fire initiation and propagation tests. For these series of tests, three were on the leading edge and one was on the

trailing edge. The FSS system runs through the leading edge dry bay and was given every opportunity to work in extinguishing a fire in the bay. The first event, the hydraulic line shot, did not result in a fire, even when it was repeated. The next two leading edge events did result in sustained fires. The maximum temperatures recorded during these two fires ranged from 980 F to well over 1000 F. The first trailing edge event was repeated and it was the repeated shot that resulted in a sustained fire. The recorded temperature was well over 1800 F and was sustained for well over 15 seconds. After the repeated fires, it was decided to skip event 5, because of funding and schedule. Test event number 6 did not succeed in damaging all the hydraulic lines with one projectile. In all the cases of sustained fires, range CO2 was used to extinguish the fires. In one test event, the fire department was called to assist in extinguishing a sustained fire on the test range.

Figure 11 shows typical damage from event 1, which was the hydraulic return line shot. The damage was pretty typical for a ductile, aluminum line under pressure.

On high speed video, the hydraulic fluid can be seen misting and spraying out of the line, as a result of the ballistic penetration. The projectile did function as it was supposed to. Again, no fire ignition occurred as a result of the shot.



**Figure 11** Typical Hydraulic Line Damage, Event 1

Test event number 2 was a front spar shot. The typical damage on the front spar shows the missing area and size of the hole. Under a typical head pressure from the fuel tank, the typical damage size allows a significant number of pounds mass per minute of fuel, through the opening, in the fuel tank.

Figure 12 shows the typical spar damage from a projectile. Note the discoloration of the spar as a result of a sustained fire. No post fire strength tests or evaluations were performed on the spar. The permanent discoloration on the spar was an indication of a temper change to the material, which implied a loss of strength.



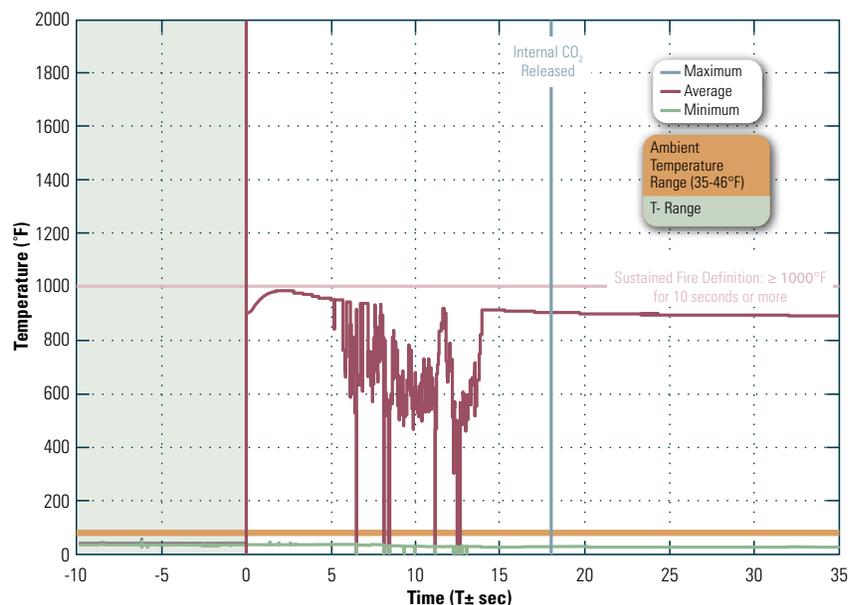
**Figure 12** Typical Damage on Front Spar, Test Event 2

While the damage is high on the spar, the head pressure of fuel is still significant. The fuel dump into the dry bay is almost instantaneous and ready for combustion. Figure 13 shows some typical ballistic damage to the upper surface of the wings. The thick aluminum structure that makes up the lower and upper surfaces of the wing does resist cracking and petaling, when ballistic damage does occur.

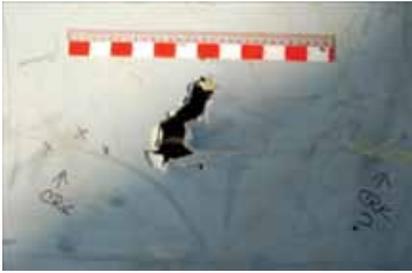
Figure 14 shows temperature readings in the leading edge dry bay during testing and the sustained fire. The reading reaches approximately 1000 F during this fire, then drops off to 900 F after about 11 seconds. There is some scatter added to the data, possibly from fire damage, during testing between 5 and 11 seconds



**Figure 13** Typical Upper Surface from Ballistic Test, Event 3



**Figure 14** Typical Thermocouple Plot for Sustained Fire on Trailing Edge



**Figure 15** Typical Fuel Tank Ballistic Damage, Inside, Event 4

into the test. The airflow through the leading edge of the dry bay did provide a small amount of convection cooling during the fire. This cooled the thermocouples slightly, but not nearly enough, to reduce damage. The slightly cooler fire could have been a result of it being pushed farther down the dry bay, away from the thermocouples.

The photograph in Figure 15 shows a picture of the ballistic damage from inside the fuel tank, rather than outside. There was some crack growth discovered about the damage area.



**Figure 17** Trailing Edge Spar Damage for Shot 6

Figure 16 shows a very robust fire where the temperatures are almost 2000 F. The duration of the fire lasted well over 10 seconds before it was extinguished with range fire extinguishing.

Figure 17 shows the damage to the surrogate test article used in shot 6. The red stick in the picture shows the path of the projectile as it traveled to the test article.

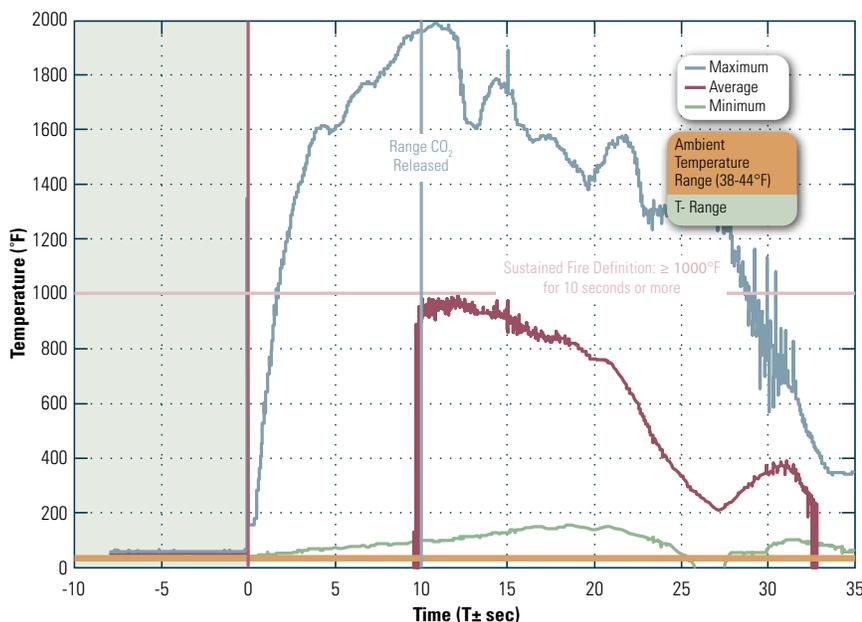
## CONCLUSIONS

Leading and trailing edges were shot five times, and three of these were spar shots. This does not produce a solid statistical foundation or a Design of Experiments vetted shot matrix from which to acquire a set of conclusions. However, five shots do provide a

snapshot from which to draw conclusions, based on solid foundation of experience of the integrated test team. The goals of testing are important to re-state here. The primary was to discover the fire probability or fire potential in the wing leading edge and trailing edges of the legacy wing. The secondary goal was to determine if the FSS, in the leading edge, could extinguish a fire in the dry bay. The tertiary goal was to see if a single, well placed shot could severely damage all three hydraulic systems line in the trailing edge.

The leading edge shots consisted of two spar shots and one hydraulic line shot. One of the spar shots resulted in a sustained fire, and the second produced a self-extinguishing fire. For the event with the sustained fire, the FSS had every opportunity to extinguish the fire but it did not. Data for the self-extinguishing fire event did not register evidence of the fire wire being triggered. For this test series, the system was hardwired into the AVSF instrumentation system to start automatically at T+25 seconds. The nitrogen was pouring into the leading edge, as in other tests, and had no effect for 14 seconds. The internal video showed ignition and fire. It soon appeared to go out on its own. Based on pre-test oxygen concentration curve, the oxygen levels in and around the fire location after 14 seconds were increasing. Therefore it is not surprising that if the fire is not stopped in the first ten seconds, the FSS will be unable to extinguish a fire in the leading edge dry bay. Technically this fire did go out on its own, but it did last longer than 10 seconds and was 20 degrees away from the 1000 F temperature. It is viewed as a sustained fire in many regards.

As designed and operated there is no FSS system in the trailing edge. The trailing edge shots were used to gauge the



**Figure 16** Typical Thermocouple Plots for Sustained Fires on Trailing Edge

potential for a fire in this dry bay. The test article was burned beyond repair on the fourth shot, so a surrogate test article was put together, and the last shot was performed on the trailing edge hydraulic systems, three closely located lines of different system circuit. In testing, the firing of a single shot was unable to severely damage all three hydraulic lines in the trailing edge at once.

## RECOMMENDATIONS

The FSS system as installed doesn't mitigate or suppress leading edge dry bay fires. At this point the recommendations are to remove the nitrogen dispersion lines in the leading edge and deadhead them in a strategic location near the wing root. This will preserve the nitrogen inerting capabilities for the fuel tank ullage, which will focus the use of LN2 in the FSS dewars tanks on their original purpose. Second, a sensorless fire extinguishing system should be investigated for leading and trailing edges of the wing. A system like FireTrace™ should be examined and evaluated for size and specific placement location(s).

The likelihood of a spar shot, in a combat environment, is a debatable topic. The bottom line is, an incendiary projectile passing through the spar of either the leading or trailing edge has a very high probability of resulting in a fire which is unlikely to self-extinguish. Removing this potential vulnerability will go far in supporting the C-5M readiness and reliability. **ASJ**

## REFERENCES

- [1] Ball, Robert E, "The Fundamentals of Aircraft Combat Survivability – 2nd Edition", American Institute of Aeronautics and Astronautics Inc., Reston VA, 2003
- [2] "C-5 Modernization Program Live Fire Test and Evaluation Detailed Test Plan, C-5M LFT&E Legacy Wing Test Program", 18 July 2007
- [3] "C-5 Modernization Program Live Fire Test and Evaluation Detailed Test Report, C-5M LFT&E Legacy Wing Test Program", 3 July 2008
- [4] "Test and Evaluation Master Plan (TEMP) for C-5 Modernization Program", Revision #2, 25 Mar 2005

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**AIAA Publications Page:** <http://www.aiaa.org/content.cfm?pageid=2>

## JCAT CORNER

*continued from page 5*

Defense-wide standard for collecting and analyzing hostile fire against US military aircraft.

As the team heads into the new year, several long-time members of the Navy JCAT are moving on to other assignments, and new members are coming aboard. CAPT Mayhew is leaving 3rd MAW in January to assume duties as the NAVAIR Reserve Program Deputy Chief of Staff for Manpower. He is relieved by CDR

David Storr, who served in Operation Iraqi Freedom in 2006. CDR Runyon will move to the NAVAIR Rapid Research and Development unit and is being replaced at 3rd MAW by LCDR Pete Olsen, who supported 2nd and 3rd MAW in Iraq in 2006–2007. CDRs Paul "Magic" Martz and Joe Toth are leaving to support NAVAIR's Program Executive Office for Tactical Aircraft (PEO-T). CDR Pete Rodriguez reported aboard 3rd MAW for

predeployment training to replace LCDR Denihan in Afghanistan in April of 2012 and will be joined by LT Calvin Martin.

We wish fair winds and following seas to our long-time JCAT members and welcome aboard our new teammates. As we move into 2012, the JCAT begins to look beyond the Iraq and Afghanistan operations to future military operations, wherever they may arise. **ASJ**

# NDIA AIRCRAFT SURVIVABILITY SYMPOSIUM

by Walt Whitesides

On Tuesday–Thursday, November 1–3, 2011, the annual NDIA Aircraft Survivability Symposium, “Survivability in a Complex Threat Environment,” was held at the Admiral Kidd Catering and Conference Center at the Fleet Anti-Submarine Warfare Training Center in San Diego, CA. Over 300 people attended this year’s event.

Tuesday was devoted to two tutorial sessions – Fundamentals of Aircraft Survivability and Radar Cross Section Reduction. That evening, attendees had the opportunity to network at an informal reception hosted at the Hyatt Regency Mission Bay Spa & Marina.

The formal Symposium was held on Wednesday and Thursday, with a Keynote Address on each day. BG Kevin Mangum, USA, US Army Special Operations Aviation Command and Mr. Paul Meyer, Northrop Grumman Corporation presented their perspectives on the Symposium theme. Each address was followed by numerous Speakers who provided threat briefings, combat lessons learned, research and development updates, methodologies for countering threats, and future requirements. A Poster Papers and Display room was also offered to all Attendees during Symposium hours. On Wednesday evening, Symposium Attendees boarded the Lord Hornblower for a dinner cruise of San Diego Harbor.

A highlight of the symposium was an Awards Ceremony held on Thursday afternoon to honor three worthy recipients. Awards were presented by BG Steve Mundt, USA (Ret), chairman of

the NDIA Combat Survivability Division and Mr. Bob Palazzo, chairman of the Awards Committee. The Combat Survivability Award for Lifetime Achievement was presented to Mr. Frank Cappuccio of Lockheed Martin Skunk Works. Mr. John Blanken of Modern Technology Solutions, Incorporated (MTSI) received the Admiral Robert H. Gormley Leadership Award. The third award, the Combat Survivability Technical Achievement Award, was presented to Dr. Donald Kenney of the Boeing Company.

Conference Co-chairs, Ron Dexter of SURVICE Engineering and Chad Sparks of Bell Helicopter Textron, are commended for making this year’s Symposium a success. Details of the 2012 Aircraft Survivability Symposium will be announced in a future edition of this magazine.

## COMBAT SURVIVABILITY AWARD FOR LIFETIME ACHIEVEMENT PRESENTED TO MR. FRANK CAPPUCCIO

Mr. Frank Cappuccio is recognized for his exceptional and sustained contributions to the field of aircraft combat



**Figure 1** NDIA Combat Survivability Division Chairman Steve Mundt, Frank Cappuccio

survivability. His 43 years of industry experience span the gamut of research, development, test & evaluation, production, and sustainment of aerospace systems and technologies, with a special emphasis on transitioning advanced technologies and capabilities into the hands of the war fighter. From his early career as an aerospace design engineer, to his final industry role as the Executive Vice President of Lockheed Martin’s famed ‘Skunk Works,’ Mr. Cappuccio has balanced pragmatic, focused and multi-disciplined development with rapid prototyping and flight demonstration, to accelerate the deployment of a broad spectrum of advanced survivability technologies: spanning aero performance, stealth, and weapons.

He has been recognized for his strategic vision, his passion for innovation, and his demonstrated skill for identifying the needs, and then communicating the 'art of the possible,' to the pilots, commanders and leadership of the Department of Defense (DoD) and the US government. He successfully executed the JSF Concept Development Phase and led the winning JSF EMD proposal team.

As the Skunk Works GM, Mr. Cappuccio had responsibilities for LM Aeronautics major programs, the U-2s, F-16, F-117, F-22, F-35, C-130 and C-5, as well as other special platforms. Under his leadership, the Skunk Works fielded the first stealthy unmanned aerial vehicle (UAV) in 2009, supporting operations in the Global War on Terror. He has received numerous company awards for his technical and programmatic leadership: he led the 2001 Collier Trophy winning JSF team for demonstrating the X-35 lift fan concept and has been recognized twice by the White House for his accomplishments and contributions to Aerospace and US air prowess.

This lifetime achievement award acknowledges Mr. Frank Cappuccio's sustained, exceptional, and visionary contributions to aircraft combat survivability, the armed forces, and the nation.

## **ADMIRAL ROBERT H. GORMLEY LEADERSHIP AWARD 2011 PRESENTED TO MR. JOHN D. BLANKEN**

John D. Blanken, group lead, Flight Test Group of Modern Technology Solutions, Inc. (MTSI) has over 35 years of experience with aerospace product development and systems integration. He has provided leadership and technical support to flight test and



**Figure 2** NDIA Combat Survivability Division Chairman Steve Mundt, John Blanken

development activities for the US's most critical and advanced aeronautical systems. His specialties include: Air Vehicle Survivability Evaluation for Low Observables and Electronic Warfare, Project/Program and Test Management, Aircraft/Missile System Development and Systems Integration, and Counter Low Observable Weapon System Development and Test. He is directly involved with and oversees engineering services in the areas of operational analysis and flight test support of low observable and electronic warfare programs. He is a recognized national-level expert in F-22, F-117, B-2 Joint Stand-off Attack Missile and F-16 survivability testing, as well as many other classified efforts. Prior to joining MTSI, he was an active duty Air Force officer. Lt Col Blanken was Commander, Special Projects Flight Test Squadron of the Air Force Flight Test Center, Detachment 3, Edwards Air Force Base, CA from 1993 to 1995. From 1990 to 1993, he was the director of Test-Space Based Interceptor program (Brilliant Pebbles) Strategic Defense Initiative Office (SDIO), Washington, DC. From 1985 to 1989, he served as the Chief, Financial Management for the Directorate of Special Programs, Secretary of the Air Force/Acquisitions Special Programs (SAF/AQL), Pentagon managing technology, development and production programs totaling \$5 billion annually. He also served as the Program Element Monitor (PEM) for the B-2

program. Through his superior accomplishments, tireless service and energetic leadership to the aircraft survivability community and to the nation, Mr. John D. Blanken is awarded the Admiral Robert H. Gormley Leadership Award for 2011.

## **COMBAT SURVIVABILITY AWARD FOR TECHNICAL ACHIEVEMENT 2011 PRESENTED TO DR. DONALD KENNEY**

Dr. Donald Kenney is a senior technical fellow at the Boeing Company. His area of technical expertise is the development of operational concepts for stealth aircraft and electronic warfare to defeat enemy integrated air defense systems. Dr. Kenney joined Boeing (then McDonnell Douglas) in 1980, and during his more than 30-year career, has worked on many advanced weapon and aircraft programs. This work has contributed to improved survivability characteristics of Boeing products. His focus has been on the evaluation of survivability in an integrated system construct; balancing reduced aircraft detection, electronic warfare, and lethal and non-lethal defense suppression. Dr. Kenney is currently the Operations Analysis Lead for Boeing Phantom Works. His analysis and survivability approaches are well known to the US Air Force requirements community at Langley Air Force Base, to the



**Figure 3** Dr. Donald Kenney, NDIA Combat Survivability Division Chairman Steve Mundt

Aeronautical Systems Center (ASC) analysis community at Wright-Patterson Air Force Base (WPAFB), and to Boeing's supplier teammates. He has supported and led many advanced program activities for space, missile, and aircraft systems and platforms with operations and effectiveness analysis. These programs include the Integrated Tactical Surveillance System, Tomahawk, SRAM II, Hypersonic Weapons, Tacit Rainbow, Light Defender JASSM, B-52 Stand-Off Jammer, J-UCAS Stand-In Jammer, and many other Boeing proprietary programs. Dr. Kenney is well deserving of the recognition associated with the Combat Survivability Award for Technical Achievement. [ASJ](#)

# WE'VE MOVED!

The Joint Aircraft Survivability Program Office has relocated to:

**Naval Support Facility—Arlington**  
**735 S Courthouse Road**  
**Suite 1100**  
**Arlington, VA 22204-2489**

For more information, contact Darnell Marbury at [jaspo@osd.mil](mailto:jaspo@osd.mil) or 703/604-0387  
Visit us online at <http://jaspo.csd.disa.mil>

Note the new phone numbers for our staff:

Dennis Lindell—703/604-2622  
Robert Lyons—703/604-5375  
Jimmy Choi—703/604-5765  
Mike Weisenbach—703/604-7118  
Ken Branham—703/604-5762  
Tim Oldenburg—703/604-7116  
Joe Jolley—703/604-2620



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# CALENDAR OF EVENTS

## APR

### 2012 AAAA Annual Professional Forum and Exposition

1–4 April 2012  
Nashville, TN  
[http://www.quad-a.org/index.php?option=com\\_content&view=article&id=31&Itemid=67](http://www.quad-a.org/index.php?option=com_content&view=article&id=31&Itemid=67)  
Add to your calendar

### JASP Principal Members Steering Group

10–12 April 2012  
Tucson, AZ

### Directed Infrared Countermeasures: Technology, Modeling, and Testing

17 April 2012  
Atlanta, GA  
<http://www.pe.gatech.edu/courses/directed-infrared-countermeasures-technology-modeling-and-testing>

### 13<sup>th</sup> Annual Science & Engineering Technology Conference / DoD Tech Exposition

17–19 April 2012  
North Charleston, SC  
<http://www.ndia.org/meetings/2720/Pages/default.aspx>

### JCAT Threat Weapons and Effects Seminar

17–19 April 2012  
Eglin AFB and Fort Walton Beach, FL

### 5<sup>th</sup> Annual Tactical Vehicles Summit

23–25 April 2012  
Washington, DC  
<http://www.tacticalvehiclessummit.com/Event.aspx?id=679266>

### 2012 Integrated Communications, Navigation and Surveillance Conference (ICNS)

23–26 April 2012  
Herndon, VA  
[http://www.ieee.org/conferences\\_events/conferences/conferencedetails/index.html?Conf\\_ID=19817](http://www.ieee.org/conferences_events/conferences/conferencedetails/index.html?Conf_ID=19817)

### 53<sup>rd</sup> AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference

23–26 April 2012  
Honolulu, HI  
<http://www.aiaa.org/content.cfm?pageid=230&lumeetingid=2414>

### Marine Corps Systems Command (MCSC) Program Executive Officer, Land Systems 2012 APBI

30 April–2 May 2012  
Norfolk, VA  
<http://www.ndia.org/meetings/2900/Pages/default.aspx>

## MAY

### 2012 MSS Electro-Optical & Infrared Countermeasures

1–3 May 2012  
Laurel, MD

### 6<sup>th</sup> Annual SpecOps Warfighter Expo WEST 2012

8–10 May 2012  
Joint Base Lewis-McChord  
<http://www.specopswest.com>

### Building Survivable Systems and Lethal Weapons: A Short Course in Live Fire Testing (LFT)

8–10 May 2012  
SURVICE, near Aberdeen Proving Ground, MD  
[www.survice.com](http://www.survice.com)

### 2012 Test Instrumentation Workshop

15–18 May 2012  
Las Vegas, NV  
[http://itea.org/files/2012/2012\\_test\\_instr\\_ws.asp](http://itea.org/files/2012/2012_test_instr_ws.asp)

### JASP Aircraft Survivability Short Course

15–18 May 2012  
Naval Postgraduate School, Monterey, CA  
<http://www.bahdayton.com/jaspsc>

## JUN

### Military Rotorcraft

6–8 June 2012  
Washington, DC  
<http://www.ttcus.com/view-conference.cfm?id=148&CFID=92348798&CFTOKEN=77478168>

### Summer JMUM 2012

12–14 June 2012  
Air Force Academy  
Colorado Springs, CO

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

SURVIAC, Washington Satellite Office  
Attn: Jerri Limer  
13200 Woodland Park Road, Suite 6047  
Herndon, VA 20171



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