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The Joint Aircraft Survivability Program Office is pleased to recognize Scott R. Wacker for Excellence in Survivability. Scott is a senior test manager for the 96th Test Wing, 96th Test Group, Aerospace Survivability and Safety Operating Location (96th TG/OL-AC), Wright-Patterson Air Force Base, OH. He is the 96th TG/OL-AC KC-46 Tanker Modernization Live Fire Test and Evaluation (LFT&E) Test Manager.

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There are ever-increasing financial pressures that acquisition programs face during the development of new military aircraft, and the situation is no different in the survivability/vulnerability community. In today’s world of shrinking defense dollars, it is imperative to do things smarter, more effectively, and more efficiently in planning and addressing live fire test and evaluation (LFT&E) requirements. When it comes to addressing aircraft vulnerability and LFT&E requirements, leveraging component qualification testing is a way to do things smarter and better as a test community.

29 WEAPONS SURVIVABILITY LABORATORY LIVE FIRE TEST & EVALUATION UPGRADES
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The Weapons Survivability Laboratory (WSL) was established in late 1969 at the Naval Weapons Center at China Lake, CA in response to significant aircraft losses during the conflict in Southeast Asia. Over the years, the WSL has grown and adapted to meet aircraft survivability testing requirements and recently made significant improvements to its capacity and capability to conduct live fire test and evaluation (LFT&E) on multiple aircraft platforms concurrently.
NEWS NOTES  By Dennis Lindell

GREG CZARNECKI RECEIVES NDIA AWARD

Mr. Gregory J. Czarnecki was recently awarded the National Defense Industrial Association (NDIA) Combat Survivability Award for Technical Achievement. Greg is a survivability subject matter expert with the 96th Test Group Aerospace Survivability and Safety Operating Location, Wright-Patterson Air Force Base, OH. His leadership, technical skills, and self-imposed demands for professional excellence have resulted in major advancements in the survivability discipline. His thorough and objective analyses combined with innovative solutions have produced clear breakthroughs in the understanding and reduction of combat aircraft vulnerability to both existing and emerging threats. His contributions have increased civilian aircraft safety and improved the ability of American soldiers to prevail in the defense of our nation. Greg’s constant pursuit for state-of-the-art improvements in aircraft survivability and his ability to deliver timely, practical, and affordable solutions have established him as a prominent authority in the national and international aircraft survivability community.

WILLIAMSEN RECEIVES NASA SURVIVABILITY TEAM AWARD

Dr. Joel Williamsen of the Institute for Defense Analyses (IDA) recently received the National Aeronautics and Space Administration’s (NASA’s) recognition for improving survivability of the Joint Polar Satellite System as member of a MicroMeteoroid and Orbital Debris (MMOD) assessment “red” team, which received NASA’s Engineering and Safety Center Group Achievement Award at an awards ceremony in Hampton, VA. NASA’s new orbital debris model incorporates huge increases in the steel particle debris population compared to previous models, which led to the formation of this team and their design of an improved protection blanket for the satellite prior to its expected launch later this year. The work of the assessment team resulted in reducing the Joint Polar Satellite System’s likelihood of critical penetration from orbital debris from 80% to less than 5%, mostly due to the improved protection blanket over the exposed wiring covering its forward-facing surfaces. This was the fifth task Dr. Williamsen has led in support of NASA. The earlier IDA tasks he did included the Columbia Accident Investigation, MMOD Risk Assessment Program Validation, Orion MMOD Protection Assessment, and International Space Station MMOD Protection Evaluation. In November 2010, NASA selected Dr. Williamsen to receive the NASA Engineering and Safety Center Leadership Award. The leadership award was given “in recognition of outstanding leadership and technical insight into the NASA Engineering and Safety Center micrometeoroid and orbital debris MMOD assessment activities.”
AIRMAN EARNs BRONZE STAR: JOINT COMBAT ASSESSMENT TEAM SERVICE RECOGNIZED

Captain (Capt) Kelli Walker, a materials research engineer in the Materials and Manufacturing Directorate, Air Force Research Laboratory was awarded the Bronze Star medal on 2 May 2014 for meritorious service as a Senior Joint Combat Assessment Team (JCAT) Officer during combat operations in Afghanistan.

While deployed, Capt Walker conducted more than 13 aircraft battle damage assessments and provided consultation on 25 hostile-fire combat damage cases to determine weapon systems and tactics used by enemy forces, enabling commanders to employ counter-tactics to defeat the threat. She also trained the United States, Australian Defense, and Afghan Forces in conducting battle damage assessments to eliminate capability gaps and increase aircraft survivability.

In one particular case, Capt Walker led an assessment team of 40 personnel at an aircraft crash site in hostile territory. According to Major General Paul LaCamera, Commanding General of the US Army’s Fourth Infantry Division, Capt Walker diligently directed the operation in rugged, mountainous terrain while under constant enemy surveillance. Her final report on the incident received the highest military and civilian leadership visibility, and resulted in the implementation of new tactics and procedures for aircrew safety and offensive operations.

“Capt Walker demonstrated courage under fire while accomplishing a vital mission. Understanding how adversaries can damage an aircraft is a crucial first step for stopping them from ever doing so again, and Capt Walker’s heroic efforts with the JCAT will save countless lives and demonstrates the powerful impact of the engineer and warrior,” Col Gloystein added.

The Bronze Star medal is the fourth-highest individual US military honor and is awarded for heroic or meritorious service in military operations against an armed enemy.
KC-46 LIVE FIRE TEST AND EVALUATION PROGRAM

by Jeffrey Wuich, P.E.
The KC-46 program is an acquisition category 1D program on the Office of the Secretary of Defense’s (OSD) Oversight List. Since the Director, Operational Test and Evaluation (DOT&E) determined that the KC-46 tanker is a covered system for live fire test and evaluation (LFT&E), the program has obtained an approved waiver to Full-Up, System Level (FUSL) Live Fire Test (LFT). To meet LFT statutory requirements, the program has developed a DOT&E-approved alternative test plan (ATP). This article presents an overview of the KC-46 aircraft (see Figure 1 for a Boeing rendering of a KC-46); the LFT&E program and Integrated Survivability Analysis (ISA) efforts to be completed in support of the ATP; and the team’s lessons learned and accomplishments to date.

**BACKGROUND**

As the initial phase of a comprehensive recapitalization strategy, plans call for the KC-46 to replace approximately one third of the aerial refueling fleet’s warfighting capability through the procurement of up to 179 aircraft. The KC-46 aircraft is a derivative of the Boeing 767-2C, based on the commercially available Federal Aviation Administration type-certified Boeing 767-200ER-IGW. It incorporates features from Boeing’s 767-300F and 767-400ER series, along with a digital flight display system from the 787-8 as well as cockpit architecture from the 767-400ER. Key features include wing-mounted refueling systems to augment the capabilities provided by the aircraft’s boom and centerline drogue system; 463L pallets, palletized seating, patient support pallets, and litter station augmentation sets to support handling cargo, carrying passengers, and supporting aeromedical evacuation; and electromagnetic pulse protection, a radar warning receiver, a tactical situational awareness system, and large aircraft infrared countermeasure system to increase the aircraft’s defensive capabilities and situational awareness.

The KC-46 is designed to provide new and upgraded combat capabilities, including the ability to operate in hostile environments with passive self-defense and protection capabilities along with the necessary battle space awareness to mitigate threats. To meet mission requirements, the KC-46 will be capable of operating from worldwide locations, both day and night, and in varying meteorological conditions. Plans call for the KC-46 to operate in the same threat environments as the KC-135 with enhanced situational awareness (SA), radio frequency threat warning, and infrared countermeasures during the departure and arrival phases of flight.

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**Figure 1** KC-46 Tanker – Key Features and Capabilities [1]
Other enhancements include built-in cockpit ballistic protection and fuel tank protection (i.e., onboard inert gas generating system). Furthermore, the KC-46 will have improved overall SA via secure communications.

**KC-46 LFT&E AND ISA PROGRAM**

The KC-46 LFT&E and ISA strategy is to conduct a comprehensive evaluation of KC-46 system-level survivability (susceptibility and vulnerability) in operational environments against ballistic and advanced threats. This strategy includes detailed modeling, simulation, and analysis (MS&A) of the KC-46 design; existing combat data; LFT of production representative assets and selected KC-46 production components (non-destructive, controlled damage, and selected ballistic testing); and data/evaluations from lab, ground, and flight tests (see Figure 2). The government will conduct an ISA to document the KC-46’s survivability against operational ballistic and advanced threats. As a subset of this ISA, Boeing is on contract to provide the government with a KC-46 Geometric Target Description and selected ballistic testing; and data/evaluations from lab, ground, and flight tests (see Figure 2). The government will conduct an ISA to document the KC-46’s survivability against operational ballistic and advanced threats. As a subset of this ISA, Boeing is on contract to provide the government with a KC-46 Geometric Target Description, vulnerability analysis inputs/outputs, and a KC-46 Vulnerability Analysis Report (VAR). The data collected from the LFT ballistic test series will be used to develop government Pcd/h values, which in turn will then be made available to Boeing in support of the contractually required KC-46 VAR. Findings from the government’s analyses and Boeing’s VAR will be documented in the KC-46 LFT&E Consolidated Final Report.

**KC-46 LFT&E AND ISA TEAM**

The KC-46 LFT&E and ISA team members and stakeholders consist of personnel from 10 key organizations and groups:

1. KC-46 Program Office
2. Boeing’s Mission Effectiveness (Geometric Target Description and Vulnerability Analysis) and System Test and Evaluation (KC-46 Design Information and LFT assets) Teams
3. 96th Test Group (TG)/OL-AC (Lead LFT&E Participating Test Organization)
4. AFLCMC/EZJA (Lead ISA organization)
5. Naval Air Warfare Center Weapons Division (NAWCWD) Weapons Survivability Laboratory (WSL) (Lead LFT&E Ballistic Test Conduct Organization)
6. Air Mobility Command (AMC)
7. Air Force Test Center (Government Lead for Developmental Test)
8. Air Force Operational Test and Evaluation (Government Lead for Operational Test)
9. OSD/DOT&E/LFT&E (LFT&E Oversight)
10. Institute for Defense Analyses

The LFT&E and ISA team consists of 130+ dedicated, career professionals that include the program office, prime contractor, government personnel, and support contractors with many years of experience, expertise, and knowledge (subject matter experts [SMEs]). There were lively discussions after contract award, but once the dust settled, the scope was defined and the tasks were assigned; the team quickly molded into a professional, productive, and functional team. The group’s cohesion allowed the completion of four ballistic test series in 14 months to fill data voids needed to evaluate 30-minute controlled flight spec compliance via the vulnerability analysis in time to support the critical design review (CDR). As the remaining ballistic test results are incorporated into the KC-46 VAR from CDR to system verification review (SVR), the uncertainty margins for the vulnerability analysis and spec compliance will decrease and the overall confidence will increase. Key lessons learned in formulating the KC-46 analysis and ballistic test team include:

- Establish a strong, positive relationship with the prime contractor and stakeholders early through honest discussion and feedback, common objectives and goals, communication regarding ongoing test and analysis results as they become available, and building upon trust.
- Involve the customer (i.e., AMC) in discussions early and often to ensure all test efforts take into account operational realism.
- Identify and bring industry SMEs onboard to leverage previous lessons learned and add to the survivability community’s knowledge base.
- Identify and bring onboard the model developers to ensure the models are being used properly, and to facilitate the improvement of the models as software change requests are identified upon exercising the models.

For the ballistic test team, the collision of unbounded ideas/theories and the limitations of test application and resources continue to be an issue, as expected. Ideas are unlimited; however, technology and resources in the test and acquisition world are limited. As such, the ballistic test team has optimized each ballistic test series to maximize test...
results by applying what is in the realm of reasonable and practical, while keeping a watchful eye out for new ideas, methodologies, and technologies to assist the program to test smarter and better and within the inherent limits of range safety, program budget, and schedule. One of the key lessons learned to optimize the value of the ballistic tests and increase confidence in the inputs to the vulnerability analysis was to apply/utilize STAT and design of experiment (DOE) principles, where applicable.

The hard work and dedication of the ballistic test team (see Figure 3) has led to the KC-46 LFT&E program being on schedule and within budget, with seven of 10 ballistic test series completed to date. FY13 was a challenging year with sequestration, travel restrictions, furloughs, and a temporary shutdown. Considering the challenges, innovation, and creativity, this team was impressive and their accomplishments were extraordinary as they overcame each obstacle. The cohesion and outstanding working relationship between the program office, 96th TG/OL-AC, and the NAWCWD WSL (e.g., outstanding Navy ballistic test support on an Air Force program) allowed the KC-46 LFT&E program to overcome these obstacles with no impact to cost or schedule. One of the key lessons learned during FY13 was that a team comprised of government and contractor support personnel provided the flexibility to overcome these challenges.

The outstanding efforts of the analysis and ballistic test team contributed to the KC-46 Test and Evaluation Integrated Product Team (IPT) (see Figure 4) being awarded the first ever, Annual AFLCMC Test Team Award in FY13.

**KC-46 ANALYSIS AND BALLISTIC TEST TEAM ACCOMPLISHMENTS TO DATE**

Working effectively with its KC-46 stakeholders, below is a list of the team’s key accomplishments to date, many of which contributed to the AFLCMC FY13 Test Team of the Year Award:

- Utilized MS&A, combined with building-block test approach in lieu of FUSL tests—“model-test-model” concept—resulting in ~$170M program savings

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KC-46 LIVE FIRE TEST & EVALUATION ANALYSES

by Rodney K. Stewart

In the acquisition of a military system, it is important to determine the extent to which it addresses the needs of the soldier and operates as intended in expected environments. The evaluation of system performance requires a careful, comprehensive approach, and often, programs will employ a combination of testing, modeling, and simulation to assess the capabilities of their systems. The KC-46 is no exception. In addition to a complete operational test and evaluation (OT&E) program, the program also has an extensive and innovative live fire test and evaluation (LFT&E) program. Its goal is to provide a thorough understanding of the survivability posture of the KC-46 aerial refueling tanker.

Historically, fixed wing LFT&E programs have primarily addressed the vulnerability posture of their systems, focusing on threat effects with little emphasis on susceptibility or engagement-level survivability issues. In response to increasing calls to integrate more information into descriptions of system survivability, the KC-46 LFT&E program has adopted the goal of considering both susceptibility and vulnerability in its assessment of the tanker. The expanded scope of the tanker’s LFT&E program will provide a fuller view of the anticipated survivability posture of the aircraft than was previously available, making this program a model for future fixed-wing programs.

Testing and analysis form the basis of the KC-46 LFT&E program. Testing provides the “truth data” needed for evaluation by revealing the system’s actual performance in tightly controlled settings. Building on the findings from testing, analysis attempts to integrate test data into meaningful descriptions of realistic operational situations. In effect, the purpose of analysis is to bridge the gap between the known (i.e., test results) and the unknown (i.e., system performance in combat). In short, LFT&E strives to provide an understanding of how a weapons system will react in various hostile environments. For the KC-46 LFT&E program specifically, the goal is to ensure stakeholders receive important information regarding the tanker’s ability to detect, deter, avoid, and withstand expected threats.

TESTING

The KC-46 LFT&E program has instituted a robust test program to provide essential data related to the ballistic vulnerability of the aircraft. The program consists of a series of 10 ballistic tests evaluating the vulnerability of the tanker against operationally relevant threats. Specifically, this test series will investigate five areas of interest for the program:

1. Projectile functioning on aircraft skin
2. Aircraft dry bay fires
3. Aircraft structural response
4. Crew station armor effectiveness
5. Engine and engine pylon vulnerability

These ballistic tests will provide insight into the KC-46’s vulnerability to operationally relevant threats as well as increase the community’s knowledge base regarding various damage phenomena, which will assist assessments of future aircraft.

ANALYSIS

In addition to testing, the KC-46 LFT&E program for the tanker includes a comprehensive set of analyses investigating the survivability of the system with respect to operationally relevant threats. This is an extensive part of the program and includes three major parts. The first effort is a series of analyses performed by Boeing, that will demonstrate the tanker’s survivability performance with respect to the system’s specifications and for various threats of interest to the program. The second effort is a series of government-led analyses forming an Integrated Survivability Assessment (ISA). The goal in this series of analyses is to evaluate the survivability of the tanker in a number of operational contexts against a variety of threat systems, not all of which are included in Boeing’s studies. The third effort in the analysis program is a series of government-led studies that address miscellaneous survivability questions posed in the alternative test plan (ATP).
When combined, these three analysis efforts will provide a depth of survivability information previously not provided by traditional LFT&E programs.

**BOEING ANALYSES**

As part of its contract with the government, Boeing will perform two kinds of analyses on the tanker. The first analysis seeks to assess aircraft’s survivability performance with respect to its specifications. The second analysis includes threats not listed in the specification but hold interest for the program office and the office of the Director, Operational Test & Evaluation (DOT&E). The results from both studies will comprise a Vulnerability Analysis Report (VAR) that Boeing will deliver.

Both sets of analyses will build upon the knowledge gained during ballistic testing by calculating the anticipated vulnerable area of the aircraft with respect to several threats. The KC-46 LFT&E program will consider the implications of these results in the consolidated VAR as well as use the data in other analyses supporting the ISA and the ATP-related analyses. Boeing’s studies, in turn, will provide a well-rounded picture for the vulnerability of the tanker.

With respect to susceptibility, Boeing’s studies will also provide data to support analyses exploring the tanker’s ability to detect and avoid a range of infrared (IR) and radiofrequency (RF) guided threats. The ISA and ATP-related analyses in particular will greatly benefit from Boeing’s work. These other studies are discussed in more detail later in this article.

**ISA**

Another major analysis effort underway in the KC-46 LFT&E program is an ISA investigating the tanker’s ability to detect, avoid, and withstand ballistic threats. This series of studies expands on the results from Boeing’s studies and will evaluate the tanker against threat systems anticipated in both current and future operational environments. This ISA (see Figure 1) will consist of the following four government-led studies that loosely correspond to the types of threats a tanker may encounter:

1. Small-Arms Survivability Analysis
2. IR Man-Portable Air Defense System (MANPADS) Survivability Analysis
3. RF Surface-to-Air Missile (SAM) Susceptibility Analysis
4. Air Intercept Susceptibility Analysis

The Small-Arms Survivability Analysis explores the tanker’s ability to survive an engagement with a lone gunner situated around an airfield used by the aircraft. This analysis investigates the probability that the gunner will hit the tanker as it flies various takeoff and landing profiles (see Figure 2 for an example of the results from this type of analysis). In addition, the analysis will estimate the probability of kill for encounters by using a process integrating the Radar-Directed Gun System Simulation (RADGUNS) and the Computation of Vulnerable Area Tool (COVART). This analysis will be the first of its kind; the combination of these tools should provide data representative of realistic encounters with the aircraft.

The IR MANPADS Survivability Analysis is a two-part study exploring the ability of the tanker to survive MANPADS engagements occurring during various stages of its mission. The first part of the study will use the Modeling System for the Advanced Investigation of Countermeasures (MOSAIC) to determine the probability that missiles will impact the aircraft in selected scenarios as well as return a list of anticipated impact locations for MANPADS threats against the tanker in a purely analytical setting. Figure 3 shows an example of output from...
MOSIAC. The second part of the study will employ the 96th Test Wing’s Guided Weapon Evaluation Facility at Eglin Air Force Base to verify the results of MOSIAC with system-in-the-loop simulations. The results of both parts of the study will be a list of missile impact points, which the LFT&E program will assess with COVART to estimate the probability of kill for each scenario.

The RF SAM Susceptibility Analysis explores the tanker’s ability to detect and avoid engagements with larger missile threats. For this study, the program will use the Enhanced Surface-to-Air Missile Simulation (ESAMS) to model how various threat systems track the aircraft and determine whether the radar-warning receiver of the aircraft provides enough response time for the tanker to avoid encounters. This study will build upon the findings from Boeing’s studies to provide a more complete picture of the tanker’s survivability against such threats.

Finally, the Air Intercept Susceptibility Analysis investigates the tanker’s ability to detect and avoid engagements with air-to-air missile threats. In this case, the KC-46 LFT&E program will use the Joint Anti Air Model to show the ability of the tanker to detect oncoming aircraft and avoid becoming a target. This study will provide useful information regarding tactics and the requirements for escorting the aircraft.

**ATP ANALYSES**

The third major effort in the analysis portion of the KC-46 LFT&E program is a host of secondary studies exploring questions of interest defined in the tanker’s ATP. These secondary studies investigate the following survivability concerns:

- The potential increase in vulnerability due to carrying munitions and other hazardous cargoes
- The expected effects of damaged landing gear on the survivability of the tanker
- The expected survivability of crew and passengers during ballistic threat encounters
- Potential vulnerabilities to high-powered microwaves, low-energy lasers, and electromagnetic pulses

These studies will round out the picture of the tanker survivability and help in the development of tactics, techniques, and procedures guiding the aircraft as it operates.

**OPERATIONAL SCENARIOS**

Supporting the KC-46 LFT&E program is a framework that places the results of testing and analysis in an operationally relevant context. A top-down approach was employed that considered the tanker’s role in future operations to build a set of possible threat engagement scenarios of interest. The program used force projections provided in multi-Service force deployment plans and integrated security constructs to determine the tanker’s roles in potential future conflicts. These roles—coupled with information from the KC-X CONEMP, KC-46 CONOPS, KC-46 STAR, combat data, and system specification requirements—then led to the development of potential missions and threat encounter scenarios, which the LFT&E program has incorporated into its testing and analysis plans. This top-down approach ensures the KC-46 LFT&E program is operationally relevant and...
reflects a more holistic approach to assessing aircraft survivability than was previously possible.

**KC-46 LFT&E Consolidated Final Report**

The KC-46 ISA and LFT&E program will culminate with the KC-46 LFT&E Consolidated Final Report, which will be delivered to DOT&E/LFT&E 120 days prior to the full-rate production milestone. The purpose of this final report is for the KC-46 to summarize the LFT&E testing and analysis and draw conclusions on the data/results. The Consolidated Final Report will be drafted throughout the course of the LFT&E program to capture all aspects of the program. The report will also include all contractor-delivered data/reports and will establish the survivability posture of the KC-46 in real-world, operational environments to ballistic and advanced threats.

**CONCLUSION**

The KC-46 LFT&E program will comprehensively explore the survivability of the tanker to a wide range of threats. Through a useful combination of testing and analysis, the program will understand the vulnerabilities of the aircraft and be able to apply this information to operationally relevant scenarios.

**References**


**KC-46 LIVE FIRE TEST AND EVALUATION PROGRAM**  
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- Utilized MS&A to evaluate aircraft subsystem vulnerability in lieu of ballistic tests on production representative assets, resulting in an additional $5.8M program savings
- Optimized LFT&E strategy by teaming with the Air Force Institute of Technology to identify and apply DOE methodologies, getting the maximum return on ballistic test series
- (First ever!) Completed five long-burn sustained dry bay fire tests on wing dry bays to understand the impact of heat transfer on structural integrity of the wing and its ability to maintain controlled flight for up to 30 minutes
- Met crew station armor operational requirement - increased aircraft payload by 894 lbs with optimized crew station armor design
- Met 30-minute controlled flight operational requirement-increased aircraft payload by 1,473 lbs with optimized body tank design

The KC-46 ISA and LFT&E team’s efforts assist in the continued success of the Air Force’s number one modernization priority, a high visibility program with intense oversight from OSD and Congress. Timely execution of the ISA and LFT schedules allows the completion of all 10 ballistic test series and analysis work in support of the SVR. After the SVR, there is 7 months to review work with the stakeholders, prior to delivering the KC-46 LFT&E Consolidated Final Report to OSD/DOT&E/LFT&E (120 days prior to the full-rate production milestone). We are looking forward to the continued success of the team as we continue to execute the remaining KC-46 analyses and ballistic test series on schedule and within budget.
The KC-46 Live Fire Test and Evaluation (LFT&E) program strategy involves a comprehensive evaluation of KC-46 system-level survivability (susceptibility and vulnerability) to ballistic and advanced threats expected to be encountered in real-world, operational combat environments. With respect to vulnerability, the program focuses on component- and subsystem-level ballistic tests designed to generate empirical data for addressing LFT&E critical issues. This data will be used for updating/generating model probability of component dysfunction given hit (Pcd/h) inputs necessary for conducting an overall vulnerability analysis of the KC-46 aircraft.

The participating test organization (PTO) for the KC-46 LFT&E program is the 96th Test Wing, 96th Test Group, Aerospace Survivability and Safety Operating Location (96th TG/OL-AC) located at Wright-Patterson Air Force Base (WPAFB), OH. Test execution support is being provided by the Naval Air Warfare Center Weapons Division’s (NAWCWD) Weapon Survivability Laboratory (WSL) located at China Lake, CA.

**TEST APPROACH**

The KC-46 LFT&E Alternative Test Plan (ATP) was developed to group tests in major test categories (see Table 1). Each of these categories, representing different vulnerability issues, was broken down into a functional test series to fully evaluate component and subsystem vulnerabilities related to these issues.

A few basic principles are being applied to the KC-46 LFT&E program to obtain a comprehensive understanding of the KC-46 vulnerability to ballistic threats expected to be encountered in combat. These basic principles include:

- Leveraging previous ballistic test programs to reduce the scope of testing by incorporating existing test data and lessons learned.

<table>
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<th>Functional Test Series</th>
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<td></td>
<td>Installed Armor Testing</td>
<td>May 14 - Jun 14</td>
<td>28</td>
</tr>
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*Table 1: KC-46 LFT&E Test Series and Descriptions*
Using a building-block test approach to screen for test variables with the greatest influence on the test response, develop empirical predictions for follow-on testing, and reduce model uncertainty.

Incorporating a model-test-model approach to help prioritize limited production test assets, increase confidence in model inputs and outputs, and explore combinations of variables not ballistically tested.

Applying a design of experiments (DOE) to increase confidence in test results and provide engineers with statistically defendable data to evaluate spec compliance; provide contractors with data needed to make aircraft design decisions; and provide the Director, Operational Test and Evaluation /LFT&E with data to develop the system-level KC-46 Integrated Survivability Analysis (ISA).

**SUMMARY OF KC-46 WING DRY BAY FIRE TESTING**

KC-46 wing dry bay fire testing used a building-block approach to evaluate the KC-46 vulnerability to ballistic threat-induced fire in the outer wing dry bays. As shown in Figure 1, empirical data and lessons learned from each test series were used to develop the test matrix/shotlines and to develop/enhance pretest predictions for subsequent test series. The culmination of data and lessons learned from these test series support the development of inputs to a vulnerability assessment, which will be part of the KC-46 ISA.

**FF-1A Skin Panel**
The FF-1A Skin Panel ballistic test series was completed at the Aerospace Vehicle Survivability Facility (AVSF) at WPAFB, OH. This test series was statistically designed using DOE principals and methodologies. A total of 299 tests were conducted and test responses were recorded to support fire and threat penetration model inputs. As seen in Figure 2, high-speed video data were captured to characterize armor-piercing incendiary (API) function duration and fragment flash duration projectile breakup, velocity change through the panels, and panel damage.

**FF-1B Replica Wing Dry Bay Fire**
The FF-1B Replica Wing Dry Bay Fire ballistic test series was completed at the AVSF, using a surrogate test article. A total of 106 tests were conducted and the test data were used to generate response surfaces from the statistically significant models for all output variables. The statistical analysis successfully identified major contributing variables and interactions driving each response variable of interest.

**FF-2A Production Representative Wing Dry Bay Fire**
The FF-2A Production Representative Wing Dry Bay Fire ballistic test series was completed at NAWCWD WSL at China Lake, CA. Production dry bay fire testing traditionally has resulted in a binary (fire/no fire) response, which provides very little insight into the ignition process. To better understand the ignition process and facilitate collecting of continuous response data, clear panels were installed in the wing dry bays to allow direct observation of the threat flash/function, fuel spurt delay, and fire ignition event within the dry bay using an external high-speed camera. A total of 57 tests were conducted, unprecedented for a production wing dry bay fire test, and the data were analyzed, along with data...
generated in the FF-1A and FF-1B testing, to develop and validate a series of Pcd/h values for use in the vulnerability analysis. The overall FF-2A test setup is shown in Figure 3.

FF-2B Production Representative Wing Dry Bay Fire Sustainment
The FF-2B Production Representative Wing Dry Bay Fire Sustainment test series was completed at NAWCWD WSL at China Lake, CA. Figure 4 shows the test setup for this test series. This test series generated data supporting a post-test residual strength analysis that evaluated the reduction or loss of KC-46 flight load-carrying capability due to outer wing leading and trailing edge sustained dry bay fires. For the first time in an LFT&E program, this sustained fire testing allows vulnerability analysts to examine assumptions regarding attrition kill levels for sustained fire on a large fixed wing aircraft.

SUMMARY OF KC-46 FUSELAGE DRY BAY FIRE TESTING
KC-46 Fuselage Dry Bay Fire testing used a building-block approach to assess KC-46 vulnerability to ballistic threat-induced fire in fuselage wing dry bays. Empirical data and lessons learned from FF-1A and FF-1B test series were used for planning the FF-3A test matrix and shotlines. Empirical data and lessons learned from the FF-3A test series were then used to plan the test matrix, down-select threats, and develop empirical pretest predictions for the FF-3B test series.

FF-3A Replica Center Wing Fuel Tank Test Series
The FF-3A Replica Center Wing Fuel Tank ballistic test series was conducted at the AVSF to determine the likelihood of fire ignition in KC-46 center wing dry bays using a replica test article and selected ballistic threats. A total of 128 ballistic tests were conducted using a series of full and fractional factorial statistical designs investigating the effects of a multitude of dry bay and threat impact variables. High-speed video (see Figure 5) was used to capture numerous response variables, including threat impact orientation, flash/function duration, fluid spurt timing, etc.

FF-3B Production Center Wing Fuel Tank Test Series
The FF-3B Production Center Wing Fuel Tank ballistic test series was completed at the WSL to examine the likelihood of ballistic threat-induced fire in KC-46 center wing dry bays adjacent to the center wing fuel tank. A total of 24 tests were conducted and the data was analyzed using statistical methodologies, along with data generated in the FF-1A, FF-1B, and FF-3A testing, to develop and validate Pcd/h values for use in the vulnerability analysis. Figure 6 presents an overview of the WSL test setup.

FF-3C Fuselage Dry Bay Fire Test Series
The FF-3C Fuselage Dry Bay Fire test series will be conducted in 2015 at both the AVSF and WSL to generate data necessary to assess vulnerability of KC-46 fuselage dry bays to ballistic threat-induced fires involving the fuselage body fuel tanks and fuel lines, and to observe and determine fire ignition characteristics and probabilities of fire ignition from ballistic impacts on the fuselage body tank.

SUMMARY OF KC-46 AIRCRAFT STRUCTURE TESTING
The KC-46 LFT&E program is using a model-test-model approach to assess aircraft structure vulnerability to ballistic threats. A detailed finite element model of a Boeing 767-200 wing, including the center wing fuel tank, was developed and numerous LS-DYNA nonlinear finite element analyses (FEA) are being conducted to

1. Identify areas of greatest uncertainty and areas where most benefit can be gained from ballistic testing
2. Assist with the test matrix and shotline development by identifying critical variables that influence the response of aircraft structural to ballistic threats
3. Determine appropriate structural loading for pretests, ballistic tests, and post-tests
4. Conduct high-fidelity pretest damage predictions and post-test residual strength analysis

Data and lessons learned from two structure-related test series (ST-1 and ST-2) and the supporting FEA results will aid in the development of inputs for the vulnerability assessment, which will be part of the KC-46 ISA.

ST-1 Production Representative Wing Hydrodynamic Ram
The ST-1 Production Representative Wing Hydrodynamic Ram ballistic test series was completed on the Atkinson Test Site (ATS) at the NAWCWD WSL at China Lake, CA. A complex test fixture and hydraulic system (see Figure 7 on page 24) were designed to load the wing to a representative 1G flight condition prior to, during, and after each test. The data are being used by modelers to first assess model credibility, and then to conduct a residual strength analysis to determine the maximum load capability (i.e., residual strength) of the damaged wing. Post-test analyses will involve additional LS-DYNA runs to produce damage data for areas of the wing that were not tested during the ST-1 test series.

ST-2 Engine/Engine Pylon Vulnerability Ballistic Test Series
The ST-2 Engine/Engine Pylon Vulnerability ballistic test series will be conducted at the NAWCWD WSL at China Lake, CA in the spring of 2015. This test program will couple testing with modeling and simulation (M&S) to determine survivability and continued aircraft safety-of-flight given a man-portable air defense system (MANPADS) hit in the engine area of the KC-46. M&S will be used early in the investigation to define MANPADS test shotlines capable of yielding combined blast, fragmentation, ram, and fire effects damage on a representative KC-46 engine and engine pylon. Figure 8 (on page 24) shows the conceptual pad layout for this test series.

SUMMARY OF CREW/PASSENGER ARMOR EVALUATION
The KC-46 Crew/Passenger Armor test program used a building-block approach to evaluate the armor effectiveness with respect to protecting the crew/passenger to ballistic impacts. Data collected from this test series is being used to support the Computation of Vulnerable Area Tool vulnerability assessments conducted by Boeing and the US Government Air Force KC-46 LFT&E Team.

AR-1, Phase I Armor Coupons Test Series
The AR-1, Phase I Armor Coupons test series was performed in Range 1 at the AVSF. A total of 96 ballistic tests were performed to examine the ballistic performance of armor panels through standardized test methodologies prescribed by MIL-STD 662F and the modified Langlie sequential firing procedure. Initial tests evaluate the armor’s performance against the specification threat and subsequent tests investigated the V50 ballistic limit for larger API threats. Remaining tests were conducted to examine armor performance near panel edges and tile seams with both normal and oblique shotlines.

AR-1, Phase II Installed Crew Station Armor Test Series
The AR-1, Phase II Installed Crew Station Armor test series was performed at the WSL at China Lake, CA. A total of 28 ballistic tests were performed to examine the ballistic performance of armor panels as installed in the production-representative cockpit. Threat shotlines targeted individual cockpit armor panels, travelling continued on page 24
Since 2007, when the Director of Operational Test and Evaluation (DOT&E) issued a directive to include occupant casualties as part of the survivability assessment of a system, prediction and evaluation of potential occupant casualties have increasingly become focal points within the vulnerability community. Unfortunately, legacy vulnerability analyses typically focus on the outcome at an aircraft level to support design and mitigation efforts and do not provide the data necessary to effectively evaluate casualty rates on board the aircraft. This CAPS article discusses the analysis parameters to be employed for the KC-46 aerial tanker as part of the KC-46 Live Fire Test and Evaluation (LFT&E) program to effectively calculate occupant casualties. The resulting calculations and metrics developed will provide insight into the greatest contributors to occupant casualties, answer the questions identified in the LFT&E alternate test plan (ATP), and provide the means to evaluate the benefit of aircraft vulnerability reduction features against occupant protection systems.

BACKGROUND

The KC-46 is the next-generation aerial refueling (AR) tanker, derived from a commercial Boeing 767-200ER series aircraft, with additional design elements from the 767-300 and 767-400 series aircraft (see Figure 1). In addition to providing AR support for a wide range of operations, the KC-46 will also support missions related to airlift, aeromedical evacuation (AE), combat search and rescue, forward area refueling point, and treaty compliance.

The objective of the KC-46 CAPS assessment is to analyze the issues identified in the LFT&E ATP, including, but not limited to, crew and passenger vulnerability due to combat threats; aircraft vulnerabilities from ballistic damage; and ballistic impacts of mission equipment, cargo, and occupant sustainment systems.

Defined techniques are built upon the CAPS methodology (JASPO-M-08-09-003) and coordinating efforts conducted by the Institute for Defense Analysis (IDA) and the Joint Aircraft Survivability Program. The analysis data will address issues identified in the LFT&E ATP related
to occupant protection and will provide metrics to investigate casualty reduction technologies. The method developed combines the use of aircraft vulnerability contributions, direct (primary) threat effects, indirect (secondary) threat effects, and historical crash/egress data to assess the overall crew survivability stance. The existing data being developed and evaluated by Boeing for the Vulnerability Assessment Report (VAR) will also be used as a base for the CAPS analysis to avoid duplication of effort. Aircraft incident data will be extracted from the National Transportation Safety Board (NTSB) accident database and will be used to develop metrics to quantify the expected number of casualties given a crash event.

**ASSESSMENT CONFIGURATIONS**

All aircraft flight phases (e.g., climb, cruise, and descent) were initially considered for the CAPS assessment (see Figure 2). The climb phase was determined to be the worst-case scenario due to the greater fuel loads; therefore, it was selected for assessment.

The KC-46 is capable of performing a full suite of missions, each having unique cabin configurations. For the CAPS assessment, a total of three mission scenarios will be addressed, representing the most common AR mission and two others where the platform provides personnel transport (both AE and personnel transport). These secondary missions represent conditions with the maximum expected number of occupants. Figure 3 depicts the mission configurations.

During AR missions, only the mission flight crew will be on board the aircraft. For this scenario, the CAPS analysis will assess the aircraft with two pilots in the cockpit and one aerial refueling officer (ARO) seated at the ARO station. The cabin will be void of any pallets or personnel. The AE mission configuration represents a scenario where the KC-46 will be used to transfer stabilized medical patients from one secured airbase to another. The personnel transport configuration is a standard mission configuration used between air bases by the Tanker Airlift Control Center.

Because the KC-46 is a commercially derived Federal Aviation Administration certified aircraft, there are a total of six doors/hatches, two of which have slides/rafts for crew and passenger egress. Military certification limits total occupancy of the KC-46 to no more than 90 occupants (14 occupants in the cockpit and aircrew member compartment and 76 occupants in the cabin). Standard 463L pallets, currently deployed by the Air Force to support a variety of mission-specific handling needs, will be incorporated into the assessment in two different configurations (see Figure 4).

**EGRESS CONDITIONS**

Egress conditions represent an end state of the aircraft after a ballistic event and account for both the aircraft configuration and component criticality due to direct threat impacts. Three unique outcomes are assumed possible after a ballistic event (see Figure 5) and described below. Each outcome may contain multiple egress event conditions. These outcomes and the occupant casualty types that
follow, initially provided by IDA, have been tailored to fit the specific capabilities of the KC-46.

- **Outcome I: Immediate Loss/No Control**—Aircraft control is lost, and the ensuing crash—caused by conditions such as uncontained fire or fuselage over-pressurization—will result in an unavoidable loss of all aircraft occupants. Due to the catastrophic outcome, the resulting probability of crew survival is a zero (i.e., no egress event).

- **Outcome II: Degraded Capability**—Aircraft control is maintained long enough to execute an emergency procedure, but the aircraft is forced down prior to returning to an accommodating airbase. This outcome may be caused by limited fuel, depleting systems, or compromised control capabilities.

The condition is defined as a forced landing event, which is a controlled “crash” on an unapproved runway/surface that occurs between 5 and 30 minutes after threat impact. Occupant survival is dependent upon the subsequent crash and egress events as determined using results gathered from the NTSB accident database.

- **Outcome III: Return to Base**—Aircraft control is maintained and the aircraft can return to an accommodating airbase to execute either a compromised landing (CL) event, resulting in additional aircraft damage upon touchdown; or a safe landing (SL) event, where the aircraft is unaffected. Additional casualties from the direct threat impact will be calculated for SL events, but calculated in a separate assessment.

The NTSB accident database will be used to determine the probability of occupant survival for a CL event.

The time intervals defined for the outcomes were correlated with standard aircraft kill levels that are being evaluated for the Boeing VAR. These time intervals were verified through discussions with the Air Force’s Air Mobility Command and Boeing to understand the timeline given a ballistic encounter on takeoff. After an encounter, the time required to return to base includes necessary steps, such as system checks, landing preparation, and obtaining clearance from the control tower.

**CASUALTY TYPES**

Casualty types represent the end state of the occupants on board the aircraft after a ballistic event. The information is accumulated for each outcome level and is the first step toward the desired metrics for the CAPS assessment. In all, there are four primary casualty types that can occur, each with the potential to exist in multiple aircraft egress conditions; however, for the KC-46 CAPS assessment, the last two categories have been combined.

- **Direct Casualty**—A direct casualty is a casualty resulting from a threat interaction with an occupant; which may include direct threat penetration, spall penetration from a threat impacting the aircraft, blast overpressure from a threat detonation, and/or burns caused by a threat explosion. Two options exist for the development of occupant casualty data: integration of legacy incapacitation data or use of the Operational Requirements-Based Casualty Assessment tool.
Cascading Casualty—A cascading casualty is a casualty not caused by direct threat effects, but rather caused by threat interaction with aircraft systems that does not result in an aircraft kill. These conditions include explosive elements (e.g., oxygen tanks, cabin fires, leakage of hot fluid, liberated equipment).

Crash-Related and Egress Casualty—A crash-related casualty is a casualty incurred during an aircraft crash event (e.g., crushing of the fuselage, acceleration injuries, liberated equipment, etc.). An egress casualty is one casualty that occurs while an occupant is escaping the damaged aircraft. This casualty could be caused by respiratory distress, burns, hindrance produced by crash, injury, etc. Both crash-related and egress casualty events occur after the ballistic damage, and the outcomes are highly dependent upon the aircraft orientation, impact surface, availability of rescue personnel, etc. The main source of data to determine the likelihood of these casualty types will be the NTSB accident database.

ANALYSIS PROCESS

To calculate the expected number of casualties for a specific ballistic engagement, vulnerability results for the aircraft must be calculated for each egress event and then combined with the expected number of casualties derived from the NTSB accident database. The probability of a specific egress outcome occurring is defined as the likelihood that a ballistic impact can produce a system failure that results in a critical aircraft event. The Fast Shotline Generator (FASTGEN) and Computation of Vulnerable Area Tool (COVART) applications will be used to calculate the aircraft probabilities. These tools simulate the progression of a projectile through the aircraft and provide a probability that a specific event will occur based upon user-defined critical components and expected failure conditions. The assessments will be conducted across the lower hemisphere to represent the most likely engagement conditions (see Figure 6).

The expected number of casualties for each condition will be determined by multiplying the number of occupants for the given mission with the average percent of occupant fatalities for similar crash conditions in the NTSB accident database. For example, consider a condition where the calculated probability of an aircraft crash is 10% and assume 100 occupants are on board. For this same condition, if NTSB data shows that 75% of occupants do not survive this type of event, the NTSB data are combined with the number of passengers to identify that the event will result in the loss of 75 passengers; therefore, when combined with the probability of the event occurring, there would be a 10% probability that 75 passengers will not survive this specific condition.

SAMPLE ANALYSIS METRICS

The analysis process described previously is repeated for each event type, as well as for the condition in which the aircraft is not affected, but individual occupants may suffer direct or cascading casualties. The data are then processed to determine the expected number of casualties for each event type given a ballistic event.

The final CAPS assessment results will be presented for each of the three defined missions (i.e., AR, AE, and personnel airlift). For each mission/event type, the following four metrics will be used to present the results of the KC-46 CAPS assessment:

1. Probability of Exactly n Casualties
2. Probability of n or More Casualties
3. Expected Number of Casualties for Any Shotline
4. Expected Number of Casualties for Any Critical Shotline

The first two metrics document the probability of each of the evaluated egress conditions (e.g., outcomes) and expected number of casualties. This information will help identify which events result in the greatest number of casualties.
casualties and the associated probability of occurrence. The data can then be used to evaluate the impact of traditional aircraft vulnerability reduction features (e.g., fire suppression, armor, etc.) on the reduction of occupant casualties. Occupant specific vulnerability reduction features (e.g., crashworthy seats, smoke evacuation systems, etc.) can be considered by adjusting the expected number of casualties derived from the NTSB data. The other two metrics provide a single value given a ballistic event that can be used for comparison to other military platforms or integrated into mission and campaign analysis tools to estimate potential casualties in a wartime simulation.

SUMMARY

The CAPS assessment approach was developed to effectively evaluate occupant casualties for the KC-46 tanker program and fulfill the request from the DOT&E. Historically, aircraft vulnerability analyses results have been reported in terms of aircraft kill levels. The CAPS methodology details the processes that will be employed to calculate the expected number of casualties for each of the possible aircraft outcomes given a ballistic encounter. In addition, three mission configurations are identified to ensure the casualty rates are understood across the spectrum of possible missions performed by the KC-46. The resulting metrics will provide insight into the greatest aircraft vulnerabilities that contribute to occupant casualties, answer the questions identified in the LFT&E ATP, and provide the means to evaluate the benefit of aircraft vulnerability reduction features against occupant casualties.

References


EXCELLENCE IN SURVIVABILITY
SCOTT WACKER

by Alex G. Kurtz

The Joint Aircraft Survivability Program Office is pleased to recognize Scott R. Wacker for Excellence in Survivability. Scott is a senior test manager for the 96th Test Wing, 96th Test Group, Aerospace Survivability and Safety Operating Location (96th TG/OL-AC), Wright-Patterson Air Force Base, OH. He is the 96th TG/OL-AC KC-46 Tanker Modernization Live Fire Test and Evaluation (LFT&E) Test Manager. As an integral member of the Joint Aircraft Survivability Program community, he is the current program manager for the fire prediction model (FPM), where he brings a wealth of knowledge and fire testing expertise to the advancement of FPM.

Scott graduated from the Ohio State University in 2001 with a BS in mechanical engineering and later continued his education at the University of Dayton (UD), where he received his MS in engineering management in 2011. While at UD, he also received certificates in systems engineering, Lean Six-Sigma, and design of experiments (DOE). He has since been recognized as a DOE practitioner within the 96th Test Wing. He has completed Air Command and Staff College, is a Level III Certified Acquisition Professional in Systems Planning, Research, Development and Engineering (SPRDE), Level I Program Management, and Level I Test and Evaluation.

Scott began his career in 2001 with the Underwater Weapons Division at the Naval Surface Warfare Center in Indian Head, MD as a project engineer working on the development of mine countermeasure technologies. In 2003, he served as the principle investigator and program manager of a joint government-industry team to develop and transition a mine countermeasure technology program, investigating the interaction of candidate hypergols and TNT, and the design of a chemical-filled penetrator to neutralize anti-tank and anti-invasion mine threats in the beach and surf zone environments. In 2005, Scott also managed an effort to demonstrate the application of high-flux plasma technology for the purpose of defeating improvised explosive devices (IEDs) and un-exploded ordnance.

In 2006, Scott returned to his home state of Ohio to continue his career at the Aerospace Survivability and Safety Operating Location, Wright-Patterson Air Force Base, OH as the Air Force Live Fire Test Lead of the C-27J/Joint Cargo Aircraft (JCA) LFT&E Program. As a member of the C-27J JCA LFT&E Integrated Product Team, he was tasked with the planning and execution of five LFT&E test series that successfully quantified the JCA vulnerability to ballistic threats likely to be seen in combat.

Beginning in 2007, he was assigned as the 96th TG/OL-AC, KC-46 LFT&E Program Manager, where he supports the KC-46 acquisition as an aircraft survivability subject matter expert, ensuring the program meets all critical LFT&E requirements and enabling the United States and Air Force to field a safe, survivable, and capable military platform.

Scott leads a diverse team of government test engineers and six support contractors in the development of a modern LFT&E approach, which combines new and innovative instrumentation and data collection techniques that result in higher confidence test results. The program has utilized a novel building-block test approach to leverage component and airbird replicas in conjunction with production representative subsystems to thoroughly characterize, understand, and validate the parameters affecting fire ignition and sustainment. Cutting-edge data collection techniques, including the innovative use of clear panels and ultra-high-speed videos to capture the fire ignition phenomenon internal to a production wing dry bay, and capturing critical, previously unknown, ballistic test data for model development and validation.
He has been a significant leader in the incorporation of rigorous scientific and statistical techniques into the LFT&E program to develop data for use in the Computation of Vulnerable Area and Tool. This approach has provided engineers with statistically defendable data to evaluate specification compliance that supplies contractors with data they need to make aircraft design decisions, and DOT&E/LFT&E with data to evaluate the system level survivability of the KC-46.

Scott is a member of the National Defense Industrial Association, a senior member of American Institute of Aeronautics and Astronautics Survivability Technical Committee, and has numerous publications related to Air Force Acquisition, LFT&E, aircraft vulnerability, and enemy threat countermeasures. He has received a number of career distinctions, awards, and letters of appreciation/commendation. He has also earned two Exemplary Civilian Service Awards in 2010 and 2011; won the Test Squadron Civilian Employee of the Year Award in 2009 and the Air Force Association Civilian Program Specialist of the Year in 2009; and was a member of the KC-46 Small Test Team of the Year Award in 2012 as well as the 96th TG General James Ferguson Engineering Award in 2014.

He lives in Washington Township, OH with his wife, Rita, and their two sons. He enjoys coaching his son’s youth sports and currently volunteers as a board member of the Centerville Baseball Softball League. His hobbies include golf, softball, and fishing.

It is with great pleasure that JASP honors Scott Wacker for his Excellence in Survivability and contributions to the JCA and KC-46 Program Offices, the aircraft survivability community, and the soldier.

KC-46 BALLISTIC TESTING IN SUPPORT OF VULNERABILITY ASSESSMENTS

continued from page 17

through several aircraft zones that presented various levels of inherent shielding.

CONCLUSIONS

The KC-46 LFT&E program is successfully meeting all defined test objectives, while simultaneously pursuing new and innovative data collection and analysis techniques. These advanced techniques are providing critical data for model development and validation and should benefit future LFT&E programs. The correlation between test results and model predictions demonstrate that the vulnerability analysis can be combined with strategic, statistically significant test programs to provide accurate platform vulnerability assessments at substantially reduced cost and schedule when compared to a test-only approach.
There are ever-increasing financial pressures that acquisition programs face during the development of new military aircraft, and the situation is no different in the survivability/vulnerability community. In today’s world of shrinking defense dollars, it is imperative to do things smarter, more effectively, and more efficiently in planning and addressing live fire test and evaluation (LFT&E) requirements. When it comes to addressing aircraft vulnerability and LFT&E requirements, leveraging component qualification testing is a way to do things smarter and better as a test community.

By planning and structuring component-level qualification tests to be more in line with realistic combat encounters, programs have an opportunity to offset risk and reduce scope and cost within their programs. During LFT&E, a benefit can be the reduction in the number of tests and shots required for assessing an aircraft’s vulnerability. One program benefiting from this approach is the United States Marine Corps (USMC) next generation, state-of-the-art, heavy-lift rotorcraft, designated the CH-53K “King Stallion” (see Figure 1). The CH-53K helicopter, currently under development, recently completed ballistic qualification tests of its sponson fuel tank design. The testing evaluated the fuel tank’s self-sealing performance and the structure’s response to hydrodynamic ram pressures caused by the projectile impact.

CH-53K FUEL SYSTEM

The CH-53K helicopter has four fuel cells that store fuel for powering the three turboshaft engines and auxiliary power unit (see Figure 2). The fuel cells are installed in the aircraft sponsons (see Figure 3) via removable side access panels. Each fuel cell is supported at four fitting locations by frangible bolts and tied to the upper skin with cord. A removable sump feature at the bottom of each cell provides the maintainers access to the majority of the internal fuel components while standing on the ground.

SELF-SEALING FUEL TANK (BACKGROUND)

A self-sealing fuel tank is a fuel cell or fuel bladder technology in wide use since World War II that prevents the fuel tanks (primarily on aircraft) from leaking fuel and igniting after being damaged by enemy weapons. Typically, self-sealing
Tanks have multiple layers of rubber and reinforcing fabric, using both vulcanized rubber and untreated natural rubber. When a fuel tank is punctured, the fuel will seep into the layers and is absorbed, causing the swelling of the untreated layer, thus sealing the puncture.

**MIL-DTL-27422 (BACKGROUND)**

The majority of military helicopter fuel tanks, designated for combat operations, are designed to the MIL-DTL-27422 specification. The specification identifies requirements and testing for determining the ballistic tolerance (self-sealing) and crash resistant performances. Testing includes evaluation of a fuel tank’s capability to seal under normal (50°F to 100°F) and cold temperature (-40°F) environmental conditions. A fuel tank or cell self-sealing capability is determined by conducting a series of ballistic shots using projectiles specified by the aircraft program. Two phases of qualification gunfire testing are associated with the MIL-DTL-27422 specification:

1. A developmental test phase (Phase I) that evaluates the basic fuel cell construction, and
2. A higher fidelity test phase (Phase II) that evaluates a more complete, aircraft representative construction, simulating an aircraft installation and the combat utility of the aircraft.

At times, the process for getting a fuel tank design to pass and meet the self-sealing requirements is more of an art than a science. Often times, it requires several iterations of tank construction and live-fire evaluations to get it right.

**CH-53K PHASE I GUNFIRE TEST**

Subject matter experts from Naval Air Systems Command Survivability and Fuel Containment groups provided their experience and knowledge in gunfire testing of self-sealing fuel tanks. They helped Sikorsky Aircraft Corporation (SAC) develop a modified MIL-DTL-27422 gunfire fuel tank qualification plan. Emphasis was given towards utilizing representative CH-53K composite sponson tank materials in place of the aluminum side wall panels called for within MIL-DTL-27422 under Phase I testing; conducting shots representative of combat encounters for the CH-53K helicopter; and understanding cold temperature self-sealing performance prior to normal temperature performance. Reasons include:

- Minimizing CH-53K program risks (schedule, cost)
- Increasing the likelihood of success for both Phase I and Phase II gunfire testing (passing the self-sealing requirement)

In 2012, Phase I gunfire testing was performed on four different CH-53K sponson fuel cell or bladder configurations. Each fuel cell tested was similar in construction with the exception of the natural gum rubber material or self-sealing layer thickness. The following approach was taken during testing:

2. Select target impact locations on the test cube that represent fuel head levels suitable to cargo type helicopter fuel tanks, meaning more challenging self-sealing requirements than the minimum 6 in head level described in MIL-DTL-27422.
The Phase I test cube configuration consisted of a flexible, reinforced rubberized fuel cell (30 in x 30 in x 24 in), four backing board sheets, four composite wall panels, and a steel frame test frame (see Figure 4 and Figure 5). Composite skin panels, representative of CH-53K sponson structure construction, were provided by SAC. The skin panels were comprised of honeycomb sandwich construction using graphite/epoxy face sheets bonded to a honeycomb core. During testing, fuel cells were filled to two-thirds capacity with aviation fuel (JP-8). To accommodate outdoor cold temperature testing, a specially constructed liquid nitrogen temperature conditioning system was fabricated for cooling the fuel filled test cube to a temperature as low as -50°F.

Self-sealing evaluation began with ballistically testing the fuel cube designs under cold temperature conditions. Upon completion, a down selection process occurred that compared each cell’s sealing capability and weight. The cold temperature tests identified two viable fuel cell designs worthy of further evaluation under normal temperature conditions. The outcome of the Phase I testing produced a single fuel cell configuration suitable for transition into Phase II gunfire testing.

The Phase I testing provided aircraft designers and vulnerability analysts an initial understanding towards the level of damage expected given a hit to sponson tank skins. The data provided members confidence in moving forward with the remainder of fuel cell qualification.

CH-53K PHASE II GUNFIRE TEST

In 2014, the CH-53K program conducted MIL-DTL-27422 Phase II gunfire fuel tank qualification testing at the Naval Air Warfare Center Weapons Division’s Weapons Survivability Laboratory (WSL) range at China Lake, CA.

Two full-scale representative CH-53K sponson fuel tank sections (forward, aft) were tested against hits from armor-piercing projectiles. The testing evaluated each tank’s self-sealing capability and structural response to an impact (see Figure 6). The cells tested matched the construction used under the previous Phase I gunfire tests. A total of 12 shots were conducted under the Phase II gunfire test.

Shotline selections were based on realistic combat engagements in an attempt to challenge the fuel tank’s capability to self-seal (see Figure 7). Shotline trajectories through the sponson tanks included upward, downward, and side engagements; entrance and exit projectile penetrations through the cell; straight and yawed or tumbled penetrations through the cell; head levels above the wounds ranging from 8 to 21 inches in depth; and projectiles passing through the fuel with distances ranging between 16 to 39 inches.

The Phase II testing was completed, providing a good evaluation of the tanks’ seal-sealing capability given a hit by a projectile. The fuel tank damage witnessed during Phase II (cell wounds, panel damage) showed similarity to the WSL’s Atkinson Test Site (ATS) was selected to support Phase II gunfire testing (see Figure 8). The site’s gun tunnel feature allowed for the fuel cells to be targeted from below, simplifying the setup and execution. Testing was streamlined by utilizing a two-gun, two-fuel-tanks setup, allowing for concurrent fuel tank testing, which saved time and cost for the CH-53K program.
damage witnessed during Phase I; however, some shots indicated differences in wound appearances and the extent of composite skin panel damage. The differences can be attributed to a variation in fuel tank shape, tank capacities, and the shotline selections.

The Phase II testing provided aircraft designers and vulnerability analysts a better understanding towards the level of damage expected given a ballistic hit to sponson tank skins.

**CH-53K LFT&E**

In the coming years, the CH-53K LFT&E program plans to conduct full-scale, operational live fire testing on a CH-53K helicopter. The CH-53K Survivability Integrated Product Team, including analysts and vulnerability test engineers, will be leveraging the data gathered under Phase II testing to reduce the number of shots, reduce the scope of the LFT&E program, and make better use of the program’s one and only full-up helicopter test article (CH-53K Ground Test Vehicle).

**SUMMARY**

It is imperative as a test engineering community to do things smarter, more effectively, and more efficiently when addressing LFT&E requirements. One simple way to do that is to leverage more on component qualification (e.g., fuel systems, flight control systems, armor systems). Leveraging on qualification tests provides the survivability community meaningful data sooner rather than later, which reduces program risk and results in cost and schedule savings for aircraft acquisition programs.
The Weapons Survivability Laboratory (WSL) was established in late 1969 at the Naval Weapons Center at China Lake, CA in response to significant aircraft losses during the conflict in Southeast Asia. Over the years, the WSL has grown and adapted to meet aircraft survivability testing requirements and recently made significant improvements to its capacity and capability to conduct live fire test and evaluation (LFT&E) on multiple aircraft platforms concurrently. Grown from a single test site in the early days, the WSL now consists of six separate test sites with an engineering and test coordination lab, machine shop, sheet metal shop, jet engine and transmission shop, welding shop, paint booth, and test article preparation area. In addition to test sites and support facilities, the WSL has improved capability in instrumentation, data acquisition, controls, video, and communication networking.

### LIVE FIRE TEST (LFT) FACILITY

Designed and built to test fighter aircraft and up-to-full-scale, transport-sized aircraft, this facility features a nine-turbo-engine, high-velocity airflow system incorporated with a 120 x 120 ft concrete test pad with a 15 ft wide by 20 ft deep gun trench running down the center to enable shots from beneath the aircraft (see Figure 1). The control building features a 24-channel event sequencer and ordnance firing system that can be used in conjunction with 96 control relays for manual or sequenced operations from the control room. There are 300 channels of standard wired data lines that can be conditioned with the available 90 signal conditioning amplifiers and six frequency-to-voltage converters. Specialty conditioning equipment includes 16 channel piezoelectric/ICP signal conditioning capability and 24 channels of strain gage amplifiers. Built-in acquisition capability includes 128 channels of standard acquisition displayed on up to four different displays and 48 channels of high-speed acquisition with capture rates up to 2.5 mega samples per second simultaneous recordings (two files). (see Figure 1)
HOSTILE FIRE INDICATION (HFI) RANGE

The HFI Range is a 20 square mile test area on the China Lake North Range that was established with funding from the Test Resource Management Center Resource Enhancement Project to enable HFI and integrated aircraft survivability equipment test and evaluation. The site's command center allows test personnel to remotely control test articles, such as a hovering helicopter mounted on top of a 20 ft tall tower and turn table with the capability to rotate 360 degrees for all-aspect sensor testing. The HFI Range has an extensive fiber optic network to support gun and missile system firing detection from multiple locations out to 4 km from the tower utilizing a mobile fire control facility, which allows sequenced firings, high-speed camera triggers, and auxiliary event sequencing. (see Figure 2)

BRACON, P-700

Modeled after LFT and constructed with BRAC 2005 funding to test fighter aircraft and up-to-full-scale, transport-sized aircraft a 120 x 120 ft concrete test pad with a 15 ft wide by 20 ft deep gun trench running down the center to enable shots from beneath the aircraft being tested. The control building is connected to the instrumentation room at the test pad via multimode fiber optics. Copper wire is not used to transmit recorded instrumentation data to the control building, making this test site unique to the other test sites at WSL. This test site is using a 144 count 62.5 um (OM1) fiber optic main trunk to stream data between the instrumentation room and fire control. Data acquisition is through national instruments, PXIC and SCXI chassis, configured to provide up to 512 channels of data recording. Of those, 128 channels have high-speed data capture with the ability to record up to 2 million samples per second (2Ms/S). Data can be transmitted at 1000BASE LX over multiple gigabit ethernet switches. P-700 contains four unmanaged 24 ports CAT6-to-fiber ethernet switches along with 32 unmanaged single port CAT6 ethernet-to-fiber switches.

The fire control building features a 24-channel event sequencer and ordnance firing system that can be used in conjunction with 96 control relays for manual or sequenced operations from the control room. (see Figure 3)

P-700 has the capability of monitoring 72 high-definition (HD) videos. This system is able to view and record resolution formats up to 1080 p at 60 fps. The site currently has 16 solid state drive (SSD) video recorders that record at an uncompressed 10-bit 4:2:2, high quality ProRes 422 (HQ), or DNxHD formats. The system records to two SSDs that can record up to 48 hours. The video broadcast grade routing switcher has the ability to quickly send live video feeds to any of the large network of LED-viewing monitors, both locally at the other test site and throughout the facility via single mode fiber optics.

VIDEO IMAGING AND RECORDING UPGRADES

World class support has always been a top priority at the WSL. As part of the constant effort to maintain this position, the WSL is undergoing a complete modernization of its video imaging support capability.

The WSL’s test pads are being upgraded to provide HD video coverage, providing over four times the resolution of the previous standard definition video cameras. New 1920X1080 60p, remotely operated cameras are supplemented with tiny internal HD cameras and ultra-high frame rate cameras with resolutions up to 1280X1280 pixels. Large 50- and 60-inch displays can also be custom configured with multiple data and video screens, allowing test crews the optimum view of test operations.

FIBER OPTIC COMMUNICATIONS NETWORK

A 144-count single mode fiber trunk interconnects the WSL’s test sites via a patch panel located at each test site in the WSL facility. This fiber optic network allows for test data to be broadcasted via a single-mode fiber from site to site throughout the WSL complex. Utilizing this fiber optic data backbone, the WSL offers an “any data, anywhere” display
architecture that allows individual camera views, or computer data displays, to be ported to and displayed on any monitor throughout the facility.

The new test article build-up facility nearly doubled the indoor preparation area at the WSL by adding an additional 5,000 square foot shop floor space. Additionally, the height capacity was increased with a 70 ft x 30 ft hanger door and a 10 ton gantry crane with a hook height of 30 ft. This facility enables the WSL to accommodate large tanker, transport fuselage, wing components, and complete fighter aircraft. The new facility significantly increases the efficiency of test preparation efforts at the WSL by increasing the size of aircraft that can be accommodated, eliminating issues resulting from adverse weather conditions and providing a safer environment in which to operate. (see Figure 5)

MISSILE ENGAGEMENT THREAT SIMULATOR

The Missile Engagement Threat Simulator (METS) is a single-stage gas gun capable of delivering a “live” man-portable air defense system to a target simulating various helicopters, transports, and fighter engagement scenarios. METS can be utilized in conjunction with the WSL’s airflow systems and all data acquisition and control systems to enable more realistic LFT&E. METS standard configuration utilizes a 6-in bore, 10-cubic ft chamber with a 2,400-psi working pressure, and 40-ft barrel. Additionally, METS is configurable to a 12-in bore, 54-cubic ft chamber (1,425-psi working pressure), and 70-foot barrel, which enables the launch of various larger projectiles, including engine blade fragments, fuses, and many other objects. METS has proven to be a versatile and reliable capability with its ability to achieve a large range of acceleration profiles. (see Figure 4)
CALENDAR OF EVENTS

MAR

JASP Subgroup Meeting
3–5 Mar 2015
GTRI–Atlanta, GA

Homeland Security Conference 2015
10 Mar 2015
http://events.jsargo.com/Home15/public/enter.aspx

Lightweight Tactial Vehicles Summit
16 Mar 2015
http://www.lighttacticalvehiclesummit.com/

Remotely Piroted Aircraft Systems Symposium
23 Mar 2015
http://www.icao.int/Meetings/RPAS/Pages/default.aspx

2015 Army Aviation Mission Solutions Summit
29 Mar 2015
http://www.quad-a.org/2015summit/

44th Annual Collaborative Electronic Warfare Symposium
31 Mar 2015

APR

31st Space Symposium
13–16 Apr 2015
http://www.spacesymposium.org/

Sea-Air-Space Exposition
13–15 Apr 2015
http://www.seaairspace.org

Aircraft Survivability Short Course
14–16 Apr 2015
China Lake, CA
http://www.bahdayton.com/jaspsc

2015 Armaments Systems Forum
21–22 Apr 2015
http://www.ndia.org/meetings/5590/Pages/default.aspx

2015 Threat Weapons Effects Training
28–30 Apr 2015
Base Theatre–Hurlburt Filed, FL
http://www.bahdayton.com/jcat/MeetingDetails.aspx

MAY

AHS International’s 71st Annual Forum and Technology Display
5 May 2015
http://www.vtol.org/events/ahs-71st-annual-forum-and-technology-display

The SpecOps Warfighter West Expo
12 May 2015
http://www.specopswest.com/Content/Welcome

Test Instrumentation Workshop and DE T&E Workshop
13–15 May 2015
http://www.itea.org/component/content/article/35-share/conferences/280-12th-directed-energy-test-and-evaluation-workshop.html#Program

IM&EM: Real Warfighter Advantage and Cost Effective Solutions Throughout the Lifecycle
18–21 May 2015
http://www.imemts2015.com/

2015 AUSA ILW LANPAC Symposium and Expo
19–21 May 2015
http://ausameetings.org/lanpac/

Spring PMSG
5–7 May 2015
Booz Allen Hamilton–San Diego, CA

Information for inclusion in the Calendar of Events may be sent to:
SURVIAC, Washington Satellite Office
Attn: Sharon Yeager
13200 Woodland Park Road, Suite 6047
Herndon, VA 20171

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