CREW AND PASSENGER SURVIVABILITY

CASUALTY ASSESSMENT AND REDUCTION—AT THE 5-YEAR MARK
page 6

Occupant Casualty M&S
page 9

Practical Approach to an Integrated Survivability
page 17
4 NEWS NOTES
by Dennis Lindell

5 JCAT CORNER
by CAPT Bill Little, USN and LTC Chuck Larson, USAF

6 CASUALTY ASSESSMENT AND REDUCTION—
AT THE 5-YEAR MARK
by Rick Sayre

Since Vietnam, the Joint Aircraft Survivability Program has supported the
development of critical technology that significantly reduced the likelihood of aircraft loss when
subjected to attack by ballistic threats. Study on rotorcraft survivability showed that the combat
hostile action loss rate for aircraft in Operation ENDURING FREEDOM and Operation IRAQI
FREEDOM was eight times lower than Vietnam, primarily because aircraft vulnerability reduction
design reduced the “cheap kills” caused by the small arms and automatic
weapon threats.

9 OCCUPANT CASUALTY M&S
by John Manion and Philip Radlowski

The goal of the Joint Aircraft Survivability Program sponsored Crew and Passenger
Survivability Assessment project (M-08-09) was to develop a methodology to assess the
survivability of aircraft personnel against hostile threats in the context of aircraft survivability.
The project had joint involvement from the Army, Navy, and Air Force. Under the M-08-09
project, the Air Force and Navy each developed methodologies to assess occupant survivability
using existing vulnerability analysis tools. As a risk reduction measure, it was decided that each
of these methodologies would undergo proof-of-concept testing.

14 SOLDIER FIRST...A NEW PARADIGM IN GROUND
VEHICLE DESIGN WITH AN EMPHASIS ON
SURVIVABILITY
by Chris Williams

Designers in the automotive commercial market have employed several methods of building
vehicle safety around the occupant. Crumple zones are engineered to absorb the force of impact
in collisions. Plastic interiors feature rounded edges to soften the blow after a crash. The industry
incorporated knee bolsters and headliners so that drivers and passengers have a greater chance
of walking away from a crash without serious injury. Historically, the US Army ground vehicles
were not engineered with these consumer-focused methods.
PRACTICAL APPROACH TO AN INTEGRATED SURVIVABILITY ASSESSMENT
by Torg Anderson and Sandra Ugrina

In November 2009, the Director, Operational Test and Evaluation issued a memorandum to his staff outlining his priorities. The Director stated, “In time of war, getting capability to those in combat must be a priority. We will contribute by participating early in the development of all systems—both rapid fielding initiatives and major programs—to provide insight on the operational and technical aspects of requirements, assure early testing discovers problems at a time when they can be fixed most easily, and help develop the tactics, techniques, and procedures our forces need to make best, immediate use of new systems.”

EXCELLENCE IN SURVIVABILITY—DENNIS WILLIAMS
by Dale Atkinson

The Joint Aircraft Survivability Program take great pleasure in recognizing Dennis Williams for Excellence in Survivability. Dennis has over 30 years of experience in the Operations Analysis Department at The Boeing Company, supporting aircraft survivability efforts. He has conducted survivability and vulnerability analyses to support Air Force Fighter competition proposals and progressed to managing the vulnerability engineering programs for the Advanced Tactical Fighter, F/A-18E/F, and EA-18G development programs.

AIRCREW COMBAT SURVIVABILITY AND CIVILIAN AIRCRAFT CABIN SAFETY: EXPLORING AND EXTENDING OUR COMMON GROUND
by Joel Williamsen and Isidore Venetos

US military aircraft are required to operate efficiently in peacetime and effectively in wartime. Some of these requirements, including cabin safety, are common to both civilian airliners and military aircraft. Some attributes, including the combat survivability of aircraft and occupants to combat threats, are unique to military aircraft; however, many design attributes that improve cabin safety can also improve aircraft survivability.

CREW COMPARTMENT FIRE SURVIVABILITY TESTING
by Patrick O’Connell and Adam Goss

Due to the many combat incidents involving helicopters during the Afghanistan and Iraq conflicts, the Director, Operational Test and Evaluation and the aircraft vulnerability community has increased their efforts to assess and improve aircrew survivability. Historically, during vulnerability testing of aircraft, little attention was given to assessing the crew’s survivability. The crew was primarily addressed during vulnerability modeling and given the same importance as any other critical component on the aircraft.
SURVIVABILITY PIONEER DON MOWRER PASSES AWAY

Donald W. Mowrer, a nationally recognized aircraft vulnerability analyst, consultant, and industry pioneer, passed away on 02 November 2012 after a brief illness. He was 87. Don will be remembered as a quiet gentleman who always had time to help share his knowledge with others and who unselfishly worked to help establish the field of survivability as a formal engineering discipline. He was a charter member of the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS), an early visionary for the Survivability/Vulnerability Information Analysis Center as well as the Computation of Vulnerable Area Tool (COVART), and a leader of numerous aircraft survivability-related efforts for more than 50 years.

Don’s career began in 1951 as a mathematician at the US Army Ballistic Research Laboratory (BRL), where he helped determine aerial target vulnerability and weapon effectiveness. From 1961 to 1973, he worked as an aerospace engineer and expert in the structural characteristics and vulnerability of US and foreign aircraft and missile systems. Through 1981, Don worked as a physical scientist and manager of numerous survivability efforts and teams, serving as chairman of the JTCG/AS Vulnerability Assessment Subgroup, chairman of the Joint Technical Coordinating Group for Munitions Effectiveness Aerial Target Vulnerability Group, chief of the Aerial Targets Branch of BRL’s Vulnerability/Lethality Division, and chairman of the international committee for the lethality testing and survivability analysis of the ROLAND missile warhead. He also authored and led the publication of a 12-volume vulnerability assessment methodology report series.

Following Don’s retirement from government service in 1981, he served as a consultant to Armament Systems Inc., where he assisted in assembling and verifying computer kill probability input data for fixed- and rotary-wing analyses, updating lethal kill criteria, and outlining a procedure for developing a database of Pk/h values for aircraft engines. Don then joined his long-time friend and colleague, Jim Foulk, at the SURVICE Engineering Company, where he worked as an employee, vice president, and then consultant, focusing his efforts on data review, organization, and analysis; damage assessment; vulnerability reduction; and methodology development and application. In addition, Don spent much time mentoring young vulnerability and survivability analysts.

In recognition of Don’s half century of contributions in the field, the National Defense Industrial Association honored him with its Lifetime Achievement Award in Combat Survivability in 1997.

Although Don will be greatly missed by many in the community, his pioneering legacy will live on in the many air systems he helped to improve, many aviators he helped to protect, and many friends and colleagues whose lives he touched.

THE AIAA PROMOTES THE DEVELOPMENT OF SURVIVABILITY AS A DESIGN DISCIPLINE THROUGH ITS SURVIVABILITY TECHNICAL COMMITTEE (SURTC)

The AIAA promotes the development of survivability as a design discipline for both air and space systems through its SURTC. The SURTC is a diverse working group of professional members from academia, industry, and government who represent the aircraft and spacecraft communities. Committee members include distinguished experts and published authors, such as Professor Robert E. Ball, who authored “The Fundamentals of Aircraft Combat Survivability and Design.” In addition, many SURTC members provide subject matter expertise in diverse applications of the survivability discipline.

The SURTC supports academic competitions for aircraft survivability design, publications in the AIAA Aerospace America magazine, development of
specifications and handbooks, and the publication of position letters on topics of interest to the survivability community. The SURTC is also responsible for the organization of the survivability sessions at AIAA conferences. The SURTC formally meets twice a year and holds working teleconferences as well. You can obtain more information on the technical committee by visiting [https://info.aiaa.org/tac/adsg/SURTCC/](https://info.aiaa.org/tac/adsg/SURTCC/)

The SURTC held its most recent biennial meeting during the evening of 23 October 2012 in conjunction with the National Defense Industrial Association Aircraft Survivability Symposium. The AIAA SURTC brings together experts in survivability from the civilian and military aerospace communities to

- Help develop and administer the survivability sessions during the yearly Structures, Structural Dynamics and Materials Conference (SDM), including the recruitment and review of conference papers
- Administer and review nominations for the prestigious biennial AIAA Survivability Award
- Conduct professional development courses, produce books, and serve as journal and book reviewers

In the Spring of 2013, the AIAA will host its 54th SDM at the Boston Park Plaza Hotel and Towers in Boston, MA from 08 – 11 April 2013. The theme of the conference will be “Materials Genome to Flightworthy Innovative Structures.” The SURTC will have one survivability session during this conference. Scientists and engineers involved in aircraft survivability are encouraged to attend this conference. Subsequently, the SURTC will participate in the 2014 AIAA Science and Technology Forum. Watch the AIAA website ([www.aiaa.org](http://www.aiaa.org)) for up-to-date information.

The SURTC is actively recruiting members with survivability expertise, particularly in the areas of crew and occupant survivability; susceptibility and vulnerability analysis; and reduction technologies. Members with expertise in rotorcraft and spacecraft survivability are needed, as well as those from the naval aviation and space communities. AIAA committees are the workhorses of the institute, and participation offers incredible opportunities for networking, resume building, and professional development. All SURTC members must be AIAA members. If you are interested in participating in the SURTC, please contact the SURTC chair elect.

**CONSORTIUM FOR AIRCRAFT SURVIVABILITY ENVIRONMENT**

The Project Management Office Aircraft Survivability Equipment (ASE), Program Executive Office Intelligence, Electronic Warfare and Sensors is in the process of researching the benefits of a consortium. The dynamics of the threat environment coupled with acquisition challenges require a different way to conduct business to provide our soldiers the best integrated and affordable protection. The consortium research effort is led by the University of Alabama in Huntsville, Rotorcraft Systems Engineering and Simulation Center. A consortium would provide a collaborative environment to bring government, industry, and academic stakeholders together to enable the aircraft survivability vision of the future. More information to follow in future issues.

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**JCAT CORNER**

by CAPT Bill Little, USN and LTC Chuck Larson, USAF

The Joint Combat Assessment Team (JCAT) continued its deployment to Operation ENDURING FREEDOM (OEF) in support of Combined Forces Aviation. During FY12, JCAT forward-deployed five United States Navy (USN) and seven United States Air Force (USAF) personnel to Afghanistan to serve with the Coalition Air Component Commanders supporting OEF counter-insurgency operations. This commitment totaled 940 man-days of Contiguous United States (CONUS) support and 1,669 man-days of outside Contiguous United States support. The Army Component executed three no-notice deployments in support of four catastrophic loss events for a total of 125 man-days.

Deployed JCAT personnel experienced an extremely busy summer and early fall as Afghanistan’s traditional fighting season ran its course. FY12 saw the JCAT conduct 223 enemy threat assessments, a 32% increase compared to 162 in FY11; this is also the new all-time record for the

*continued on page 23*
CASUALTY ASSESSMENT AND REDUCTION—AT THE 5-YEAR MARK

by Rick Sayre
Since Vietnam, the Joint Aircraft Survivability Program (JASP) has supported the development of critical technology that significantly reduced the likelihood of aircraft loss when subjected to attack by ballistic threats. The 2009 study on rotorcraft survivability showed that the combat hostile action loss rate for aircraft in Operation ENDURING FREEDOM (OEF) and Operation IRAQI FREEDOM (OIF) was eight times lower than Vietnam, primarily because aircraft vulnerability reduction design reduced the “cheap kills” caused by the small arms and automatic weapon threats. [1]

The human fatality rate associated with combat hostile action losses also showed a reduction from Vietnam to OEF/OIF, but not to the same extent. Some of this decrease in the fatality rates can be attributed to having more survivable aircraft, but improvements in airframe crashworthiness and crash protection for passengers are necessary to further reduce fatalities and injuries.

Table 1 displays the Department of Defense (DoD) rotorcraft fatalities from October 2001 through August 2012 (OEF/OIF time frame). There were four types of fatalities seen in the combat data: those that were a result of threat effects directly hitting the person; those that were a result of a catastrophic crash; and those that were a result of a survivable crash, and those where the cause of the fatality is attributed to both threat impacts and crash effects (a catastrophic crash occurs when no crewmembers or passengers survived after the aircraft crash, and a survivable crash occurs when at least one crewmember or passenger survived after the aircraft crash).

We should continue to focus on technologies that reduce fatalities when the threat or threat effects directly hit pilots, aircrew, or passengers; however, data shows that 207 fatalities come from survivable crashes. Clearly more effort is needed in improving crashworthiness, which is a common area of interest between the safety and live fire test and evaluation (LFT&E) communities, and both communities should work together to reduce casualties. Additionally, one of the primary ways to reduce fatalities from catastrophic crashes from combat incidents is to prevent the event from occurring by reducing the susceptibility or vulnerability of the aircraft. Fatalities from survivable crashes can also be reduced by preventing the crash from occurring, but they can also be reduced through a combination of improvements in crashworthiness and egress.

Five years ago, guidance was issued to JASP to broaden their scope and refocus their efforts, and to work in concert with the aircraft safety community to predict and reduce combat-related occupant (passenger and crew) casualties. In support of this effort, JASP was directed to

- Conduct background investigations into the causes and types of occupant casualties, using combat and safety-related incident data
- Assess potential for occupant casualties in joint LFT&E, which may include specialized crash and/or egress-related testing
- Develop/expand tools that predict probability/number of casualties, crash conditions at landing, and crash effects on occupant, including failed egress
- Identify and evaluate new casualty reduction features for aircraft considering crashes, hard landings, and ditching at sea
- Coordinate with other organizations within and outside the DoD (e.g., Acquisition Technology and Logistics, Safety Centers, Department of Homeland Security, Federal Aviation Administration [FAA], National Aeronautics and Space Administration [NASA]) to accomplish these goals

JASP has pursued many of these efforts that improve casualty assessment and reduce casualties, each with some degree of success. The Joint Combat Assessment Team has expanded its mission to examine and record the causes of combat casualties in existing combat theaters. Joint live fire testing to determine the extent of casualties that are associated with cabin-induced fires in large transport helicopters, including
heat, toxic smoke, and oxygen depletion. This effort may lead to new technologies or operational protocols to reduce fires or improve occupant survivability until a safe egress after landing. Two casualty prediction methodologies have been developed based on existing Computation of Vulnerable Area Tool (COVART) and Modular Unix-Based Vulnerability Estimation Suite (MUVES) models to support aircraft vulnerability evaluation programs. One of the methodologies is being utilized in part to support passenger casualty evaluations for the KC-46 following ballistic impact. Improved crew armor, cabin fire reduction, and crashworthy seat technologies have been pursued and show promise for further reducing casualties. And finally, JASP is working with NASA and the FAA to test and integrate aircraft safety features that might reduce aircraft casualties following ballistic attacks.

Despite the JASP advances made towards establishing a framework for casualty assessment, several important model and test capability gaps exist that limit the direct application of these techniques for reducing casualties. The two highest priorities for development include determining the changes to flight performance and controllability of the aircraft following ballistic damage that can be used in flight simulations and models to provide potential ground impact conditions, and examining indirect effects (smoke, fire, toxic gases, etc.) to quantify the impact on casualties during continued flight operations and occupant egress after landing. Other important efforts that JASP and the live fire community must support include the following:

▶ A closer examination of the cause of casualties in military aircraft (and civil aircraft platforms of similar construction) using combat and safety-related
incident data. It is important that relevant medical data be collected and reviewed to focus on areas that cause the greatest number of injuries and fatalities. Joint programs planned with the FAA hold significant promise for this, but a more in-depth evaluation of military aircraft safety and combat data is warranted.

▶ Development of a set of guidelines outlining the casualty assessment methodology that will standardize practices used to assess aircraft occupant survivability. These guidelines should include: definitions, terminology, metrics, objectives, assumptions, limitations, ground rules, standard vignettes, best practices, and data needs that could lead to required testing. A similar set of guidelines is currently under development within the Director, Operational Test and Evaluation for evaluating ground vehicle casualties, and some commonality should be seen between the ground vehicle and aircraft communities. From these guidelines, appropriate testing requirements should be developed that will be included in future test and evaluation master plans.

▶ Establishment of baseline occupant survivability assessments for the current fleet of rotorcraft and transport aircraft. If new technologies are to be incorporated, they must show that they reduce fatalities and injuries. The Army’s new Full Spectrum Crashworthiness Criteria for Rotorcraft [2] provides an excellent starting point for establishing baselines for rotorcraft, and similar criteria should be developed (with assistance from the FAA) for transport aircraft. Although ejection seats on tactical jet aircraft eliminate many of the concerns for crashworthiness, baseline crew survivability assessments should still be established.

Acquisition decision makers, system designers, and requirements writers need quantifiable casualty predictions to evaluate applicable technologies and procedures that reduce occupant casualty risk after initial aircraft hits. Although aircraft survivability evaluation methodologies have historically focused on what happens to the aircraft in a combat event (with only a limited consideration of personnel casualties resulting from combat-induced aircraft losses), JASP has demonstrated that these methodologies can be modified to include the prediction of casualties to the point of egress prior to or following a hard crash or safe landing.

The assessment of aircraft occupant casualties to the point of safe return or egress continues to be an important element of LFT&E, including the evaluation of personnel casualties due to combat-related, in-flight escape and crash events. JASP’s portfolio of efforts to reduce the onset of aircraft losses through vulnerability reduction, susceptibility reduction, and survivability modeling will be enhanced by these new efforts to reduce occupant casualties. Reducing casualties is and continues to be of paramount importance to the DoD, not only for aircraft, but for ground vehicles and ships as well. This cross-platform emphasis on casualty reduction technologies will identify common areas of research applicable to aircraft, ground vehicles, and ships. }

continued on page 13
The Conditional Probability methodology was developed to assess crew and passenger casualties while leveraging existing aircraft vulnerability tools and methodologies. Significant effort and resources have already been spent evaluating aircraft vulnerability, which is a key factor in assessing personnel survivability and casualties. The first part of the methodology captures the effects of direct threat impacts on the aircraft and personnel. The purpose is to quantify the end state of the aircraft. This is accomplished using the probability of kill (P_{k}) for each time-based kill level modeled, and using a Weibull distribution to account for the time in between kill levels. This methodology requires the analyst to make correlations between the kill levels and the corresponding end state(s) of the aircraft (Figure 1). These correlations are based on multiple factors including the aircraft type, mission, and operating environment. The impacts of the threat on all the aircraft systems and personnel are also captured. Certain aircraft systems can result in secondary effects in personnel areas such as fire, smoke/toxic fumes, etc. and may result in personnel casualties.

The second part of the methodology quantifies the probability of casualty (P_{c}) for each person based upon the end state(s) and resulting egress type(s) corresponding to the end state. For example, an aircraft that is predicted to fall out of manned control in less than 30 minutes may attempt a hard landing, order an air egress of all personnel, or be able to land at the base. Multiple factors contribute to the determination of casualties for each end state and egress type.
The result of the methodology is a Pc for each person on the aircraft. These Pc values can be reported to support multiple different metrics. For example, the Pc of one or all personnel or the Pc for a particular person could be reported. The conditional probability methodology has not yet been integrated into the vulnerability codes. As a result, the calculation of other metrics (e.g., Pc of 10 and only 10 personnel) is tedious, but possible.

A PoC analysis was conducted using the Conditional Probability methodology. The methodology was executed with the Fast Shotline Generator and the Computation of Vulnerable Area Tool vulnerability codes. A transport aircraft was used as the test bed for the analysis to model predicted casualties of passengers. The aircraft and personnel were assessed against a high explosive round. The explosive nature of the threat exercised multiple damage mechanisms for a more robust testing of the methodology.

Multiple changes were made to the aircraft model to test the various attributes of the Conditional Probability methodology. Twenty persons were added to the main cargo area. Two components with potential secondary effects were modeled. There was a number two engine (uncontained engine debris) and a hydraulic reservoir (fire) in the main cargo area. The secondary effects components allowed for the analysis to assess the impact on personnel in addition to the effect on the aircraft. Not all potential secondary effects components were modeled for the PoC analysis.

The PoC analysis involved significant amounts of estimated data to populate the various casualty contributing factors. Potential sources for this data are available and were identified in the Aircraft Combat Occupant Casualty Assessment State of the Art Report (JASPO-M-08-09002). Other factors such as the impact conditions and resulting loads on the personnel are more difficult to determine.

The PoC analysis demonstrated that the Conditional Probability methodology could be successfully executed. Sensitivity studies were conducted to better understand the parameters that most affected the results. In the process of conducting the analysis, methodology bugs were identified and the lessons learned were documented in the PoC report (JASPO-M-08-09-004). Because of the input data estimates, the results cannot be considered authoritative; future crew casualty analyses will need to better quantify the casualties due to ground impact along with other contributors outside of the typical aircraft vulnerability analysis.

Provided the input data is developed, the Conditional Probability methodology is capable of serving as the basis for aircraft personnel casualty analyses. The methodology and PoC analysis provide a framework where future analyses can be conducted. The Conditional Probability methodology also has the ability to easily expand to accommodate additional casualty contributing factors that may be the result of different aircraft, different operating conditions, or from an increased knowledge base of these factors.

INTEGRATED CAPS METHODOLOGY

The goal of the Integrated CAPS methodology was to develop a process that includes occupant casualty as a vulnerability design consideration, can be performed within the aircraft acquisition process, and uses existing vulnerability data and tools as much as possible. The Integrated CAPS methodology achieves this goal by building from the existing vulnerability analysis process and data. It uses the same methods, tools, and input types as the current vulnerability assessment process. The key to the Integrated CAPS methodology is the fault tree.

The fault tree for the Integrated CAPS methodology builds from existing vulnerability data, but changes the focus from the aircraft to the occupant. Each occupant is treated as a system whose state depends on the damage types listed in Table 1.

The top level of the Integrated CAPS methodology fault tree focuses on the aircraft damage types (Aircraft Damage in Table 1). These damage types affect the occupants in different ways. For example, one damage type considered in the PoC testing was catastrophic aircraft damage. This damage will affect all occupants globally in that no one occupant will survive. Other aircraft damage types, such as damage that results in specific crash conditions, may affect each occupant differently. In these cases, the fault tree must be expanded to include the effects of the threat and crash conditions on each occupant and must also consider all of the damage types listed in Table 1.

The resulting fault tree is highly complex. Figure 2 shows an excerpt of the resulting fault tree on a notional aircraft with five levels of aircraft damage identified.

In Figure 2, the top level of the fault tree is the probability of N or more casualties. There is one fault tree constructed for each N (N=1,2,3; total number of occupants). These probabilities are then combined to into one top-level metric called Expected Number of Casualties.
The Expected Number of Casualties is a single number that, like the standard Vulnerable Area metric, relates the value to a specific threat condition (e.g., man-portable air defense system missile impacting at a specific velocity). This single value supports design trade studies as illustrated in Figure 3.

In addition to the Expected Number of Casualties, samples of other information attainable from the Integrated CAPS methodology are shown in Figure 4.

The various outputs of the Integrated CAPS methodology allow for the determination of key areas to focus
vulnerability reduction designs. This was demonstrated in detail as part of the Navy’s PoC testing. [1]

The Integrated CAPS methodology was implemented in the Advanced Joint Effectiveness Model (AJEM) vulnerability tool. AJEM was selected due to its highly flexible and adaptable fault tree input and interrogation algorithms that were necessary to implement the Integrated CAPS methodology. The Integrated CAPS methodology examines all of the PN-or-More-Casualty fault trees for each threat interaction in AJEM. AJEM then rolls up the probabilities over all of the possible threat interactions and provides metrics to directly compute the Expected Number of Casualties. AJEM also directly provides all data shown in Figure 4.

**Figure 3** Illustration of Use of Expected Number of Casualties

**Figure 4** Examples of Outputs from Integrated CAPS Method
PoC testing by the Naval Air Systems Command (NAVAIR) Combat Survivability Division was successful in demonstrating the Integrated CAPS methodology’s capability to assess occupant survival probabilities and support design trade studies. Details of the methodology and testing results are documented in the JASP report titled “Crew and Passenger Survivability (CAPS) – Methodology and Proof-of-Concept Testing.” [1]

FUTURE DIRECTIONS

Although the PoC testing of the Conditional Probability and Integrated CAPS methodologies were completely successful, there are specific inputs identified from both methodologies that require further examination. Referring to Figure 2, the data in the green circles represent various conditional probabilities that had to be assumed during the Integrated CAPS PoC testing. Identical parameters were identified in the Conditional Probability methodology as well. Determining the actual values for these conditional probabilities will require significant efforts in areas of expertise outside of the vulnerability discipline.

At the initiation of M-08-09, a state-of-the-art report was published (JASPO-M-08-09-002), which identifies the potential organizations that can help in generating these conditional probabilities. Following this PoC testing, the state-of-the-art report is being updated and a road map is being generated to develop methodologies that will produce valid values for these conditional probabilities. [2]

References


Historically, the US Army ground vehicles were not engineered with these consumer-focused methods. Legacy vehicles featured the “survivability onion” concept, which took an outside-in approach to vehicle safety, following the philosophy of “don’t be seen; if seen, don’t be acquired; if acquired, don’t be hit; if hit, don’t be penetrated; if penetrated, don’t be killed.” That philosophy worked well when vehicles were designed primarily for force-on-force frontal attacks.

In this new era of persistent conflict and close-in asymmetric threats, that mentality is no longer valid. Improvised explosive devices (IEDs) have changed the picture. IEDs not only have the potential to destroy vehicles, but blasts below the hull often throw soldiers inside the vehicle, where sharp edges, exposed wires, loose objects (pry bars, ammo, etc.), and hard steel can cause serious secondary injuries or death.

The Army has determined that quick-response solutions help, such as increased armor, different belly plates, or new hull designs, but they are not optimal. Instead, vehicle design must be rethought, from the inside-out, with the focus on keeping soldiers alive and safe.

RETHINKING SURVIVABILITY

The Army’s Force Protection Occupant Centric Platform (OCP) Technology Enabled Capability Demonstration (TECD), led by the US Army Tank Automotive Research, Development, and Engineering Center (TARDEC), began in FY12 and is scheduled to continue through FY15. The OCP TCD will set the Army standard in creating vehicles, and it includes the following:

► Increased protection from current and emerging threats
► Optimized interior space for soldiers and gear
► Decreased technology weight
► Maintained maneuverability
► Full-spectrum operational design

The OCP TCD gave engineers the opportunity to re-examine ground vehicle design with a greater emphasis on occupant protection, leading them to step back and ask vital questions: How should vehicle interiors be designed? What materials should the armor contain? What exactly happens during an IED blast and how do vehicle occupants respond? How well do various technologies protect soldiers from injury and death? How do we take all this knowledge and integrate these new technologies without sacrificing size, weight, power, and cooling in a system?

SETTING STANDARDS WITH A CAMEL

Of the deliverables defined by the end of the OCP TCD, the most important will be the creation of an overarching military standard—including design guidelines, technical specifications, and test operations procedures—that is titled...
storage will be examined to determine how to best integrate these features into the system to offer maximum protection.

“All of these technologies are being worked up front,” remarked Knott. “Right now we’re still early in the process. December 2012 is when we’re scheduled for Preliminary Design Review, when we expect to see a preliminary glimpse at what’s in and what’s out. I can tell you there are going to be seats, but what does the seat need to do? Those are the things that we’re working through.”

The CAMEL will be a prototype demonstrator, not designed for production, but to show what optimal protection looks like. The TEC’s third and fourth deliverables will take the CAMEL’s concepts and how to apply them to platforms for lightweight and heavyweight vehicles to show how they may impact current and future systems. “We’re picking the Mine-Resistant Ambush-Protected All-Terrain Vehicle as a light platform and the Bradley as the heavy class platform to take what we’ve learned and determine the impact on current systems,” Knott explained. “The program’s focus is to get the standards in place to set the Army up for the future.”

**MODELING SOLUTIONS**

Advanced computing systems have been valuable tools as GSS engineers develop these new standards. In the past, engineers took a trial-and-error approach, using expensive prototypes and lengthy experimentation to discover which technologies and methodologies worked best.

Recently, Heidi Shyu, Acting Assistant Secretary of the Army (Acquisitions, Logistics and Technology) and Army Acquisition Executive, emphasized that using modeling and simulation (M&S) to solve development issues will benefit the Army.

“As our budget realities present funding constraints, there is a real need for processes that save both time and money in expediting the fielding of needed equipment,” Shyu stated. “Increased reliance on high-fidelity modeling and simulation technology can shorten development schedules by eliminating unnecessary testing and reduce sustainment costs by enabling realistic training for soldiers responsible for maintaining weapon systems. These and other lessons from the past decade of combat are integral to our future equipping efforts, regardless of the threat.” [1]

Today, TARDEC’s advanced M&S capabilities allow hundreds of virtual experiments to run in a short amount of time before a single piece of metal is bent to fabricate a prototype. Over the past decade, this capability has been advanced and refined to provide an in-depth, accurate, and indispensable tool to better understand how soldiers and vehicles react during blasts, crashes, and rollovers.

“Seven or 8 years ago, we had very basic models and computational tools to address blast issues. Now we have full-fledged suites of computational tools to address not only occupant injury risk assessments, but also structural performance at a system level,” remarked Sudhakar Arepally, Deputy Associate Director for TARDEC’s Concepts, Analysis, Systems Simulation, and Integration Analytics Team. “We have a top-of-the-line, advanced computational and high performance computing environment. We are able to deliver computational results to the customer much faster. What would once take months, we are now able to deliver in a
few weeks based on advanced modeling techniques, experienced staff, and upgraded computing platform.”

A better approach to occupant survivability begins with a better understanding of vehicle occupants themselves. Models previously depicted soldiers as one body type and build, and did not account for how the increased gear that soldiers carry impact their posture, which greatly contributes to injury. By examining various types and sizes of soldiers in a variety of postures and seating configurations, TARDEC’s M&S experts can better understand how occupants react in emergencies.

“Once the impact at the underbelly occurs and the shockwave propagates through the vehicle, you have turbulence inside the occupant compartment, where different body regions experience different impact scenarios,” explained Arepally. “We collaborate with the RDECOM [Research Development and Engineering Command] and the Army Research Laboratory to leverage their science and technology capabilities, and OEMs [other equipment manufacturers]/suppliers to harness their product knowledge, data, and models.”

Advanced computational M&S has also led to a greater understanding of how blast events occur and how they affect the vehicle. During IED blasts, a complex series of events occur in the blink of an eye, and everything from charge depth, soil compaction, armor materials, and hull shape can impact the way vehicles and occupants react. TARDEC’s M&S tools allow engineers to be better prepared to conduct experiments with hull shapes, blast variables, and occupant orientation to understand what happens in a blast event, how it affects vehicles and occupants, and what solutions may yield the best results. “We are looking at the system level—the entire vehicle, including tires, chassis, powertrain, seating, seatbelts, and airbags. In one computational run, we are able to look at the entire system-level performance; it’s a big step from where we were,” Arepally commented.

“But our models still don’t take into account the variability and uncertainty involved in this complex phenomenon. The way the soil is placed, for instance, depends on the soil’s compaction, moisture content, and granularity. That all must be perfectly aligned, because even if it deviates a little bit, the end result will be affected,” Arepally continued. “What we are trying to understand at this point is how much it will be changed or affected by the soil parameters. And the entire blast-kill chain comprises of different things [such as] soil, material properties, and manufacturing variability. As a result, the challenge that we persistently face is to improve predictive capability of the models.”

These capabilities will help GSS engineers understand how to best design vehicles to prepare for blast events. “Your car is designed to put you in a position,” remarked Knott. “A lot of people don’t understand the engineering involved in a car to help position the occupant appropriately to ride the crash down. Things like side-cushion airbags or airbags that come out of the door to put the person in position to ride the crash.

“The models allow us to get a rough order of magnitude of potential technologies. It helps us whittle down to a right answer,” commented Knott. “It’s not the answer, but it helps us know we’re in the right ballpark. M&S tells me what stadium I’m in, but then I have 30,000 seats inside where I can sit.”

The information gleaned from computational analysis will help GSS as it develops the Army’s occupant-centric survivability standard. At the end of the program, the Army will have standards in place to properly design vehicles that allow all crewmembers to safely complete missions. In addition to the Army standards and the three demonstrator vehicles, the greatest deliverable of all will be seen in the soldiers who return home safely because of the work done by the Army’s engineers and their partners.

The technology thrust areas for the “Occupant Centric Survivability Demonstrator” include the following:

- Hull shaping and materials
- Absorption materials
- Reduction of hard points
- Stowage
- Air bags
- Innovative ergonomics ingress/egress
- Effective seating
- Fire suppression systems
- Restraints
- Vehicle sensing and electronics
- Mobility systems/active safety

References

A PRACTICAL APPROACH TO AN INTEGRATED SURVIVABILITY ASSESSMENT

by Torg Anderson and Sandra Ugrina

In November 2009, the Director, Operational Test and Evaluation, (DOT&E) issued a memorandum to his staff stating that “In time of war, getting capability to those in combat must be a priority. We will contribute by participating early in the development of all systems—both rapid fielding initiatives and major programs—to provide insight on the operational and technical aspects of requirements, assure early testing discovers problems at a time when they can be fixed most easily, and help develop the tactics, techniques, and procedures (TTPs) our forces need to make best, immediate use of new systems.”

To enforce this priority, the Director laid out four initiatives: (1) field new capability rapidly, (2) engage early to improve requirements, (3) integrate developmental, live fire, and operational testing, and (4) substantially improve suitability before initial operational test and evaluation (IOT&E). The third initiative is directly applicable to an Integrated Survivability Assessment (ISA) because such an approach depends on data from developmental, live fire and operational testing. Early engagement and planning inherent to a successful ISA also helps to ensure an improved and more efficient assessment, expediting the overall fielding process.

LIMITATIONS TO PREVIOUS ISA CONCEPTS

An ISA approach has been of interest to DOT&E since the early 1990s. Several reports published in the last 20 years have dealt with the methodology of an ISA. These studies provided thoroughly defined ISA approaches that focused on solving all elements of the kill chain equation for each chosen mission scenario. The Joint Aircraft Survivability Program (JASP) even developed a generic checklist and a hierarchy of metrics for such calculations. They determined how the metrics would be evaluated using existing models and simulations (M&S) and test ranges; however, given the magnitude of recognized M&S deficiencies and uncertainties in assessing each element in the kill chain some researchers have concluded that “significant resources are required to mature and fully implement the ISA process”. DOT&E did not adopt any of these approaches as a standard practice.

Meanwhile, understanding what constitutes an “integrated” assessment has varied within the survivability community. Approaches implemented in earlier acquisition programs have often been limited to merely assembling otherwise independently collected developmental, live fire, and operational test findings into one document. For various reasons, including conflicts in the acquisition schedule, such approaches have not been efficient, did not uniformly consider all relevant conditions or findings, and resulted in last-minute issues whose resolution had become impractical and costly. More importantly, such federated findings could not easily be interpreted in a context that would be valuable to decision makers and operators.

Successful implementation of an ISA concept has been limited by several more general issues.

Issue 1: Survivability is highly dependent on the operational context.

While the common meaning of survivability is a simple and clear “ability to stay alive,” assessing survivability of a Department of Defense (DoD) acquisition product is not a straightforward task. System survivability cannot be assessed without first identifying the operational context in which the system is used, including the types, capabilities, and probable distributions of expected threats. Because system survivability is dependent on those multiple factors, it will vary, sometimes significantly, as operational and engagement scenarios...
change. Furthermore, a simple probabilistic approach to the elements of survivability can be misleading if operational co-dependencies are not considered; averaging probabilities across all operational scenarios will more than often result in an unreliable estimate of the probability of survival.

**Issue 2: Although survivability is divided into two major elements (susceptibility and vulnerability), aspects of it are typically assessed by three different entities.**

Some of the fundamental capabilities and performance of survivability-related system features are assessed during developmental test and evaluation (DT&E) as subsystems mature; however, evaluation of these subsystems as part of the whole acquisition product and in an operational environment is not normally performed until operational test and evaluation (OT&E). Although OT&E can be performed concurrently with DT&E efforts, concurrent testing is not necessarily integrated testing, and OT&E might discover problems in the performance of survivability-related features when tested in operationally realistic environments that the requirements do not consider. Assessment of vulnerability is normally performed during live fire test and evaluation (LFT&E), although some vulnerability-reduction features may be assessed during developmental and operational testing; however, LFT&E must ensure that test conditions correspond to operationally realistic scenarios for consistency with operational assessments. By itself, however, this architecture does not result in a comprehensive integrated assessment, and despite significant test and evaluation efforts, the lack of coordination and integration can significantly depreciate the value of individual findings.

**Issue 3: A balanced approach to integrating susceptibility- and vulnerability-reduction features in the aircraft is not always carefully considered in the system design process.**

The mix of survivability technologies or techniques and synergies between them is typically not optimized for a given platform. The design approach chosen early in the program directly influences the extent to which susceptibility- and vulnerability-reduction are integrated. A distributed design approach can cause difficulties in characterizing the integrated effects of platform capabilities on overall survivability, naturally translating into disparate assessment approaches later in the acquisition process.

**Issue 4: “A number of deficiencies have been identified in the ability of open-air test ranges to support an integrated survivability assessment.”**

Limited capabilities of the open-air test ranges was one of the deficiencies listed in the 2003 JASP report on ISA. It was rightfully argued that range test data were not suitable for model validation. Consequentially M&S tools, which are “glue” that holds the integrated survivability assessment together,” include uncertainties and are not credible enough to bring together various elements of the survivability assessment where those uncertainties will multiply.

**NEW ISA CONCEPT**

**Objective**

In an attempt to define a more practical approach, DOT&E requested an example ISA concept to be developed for a current DoD program in each of three warfare areas (land, sea, and air). This resulted in a concept based on the premise that calculating all elements of the kill chain equation, as was attempted in previous ISAs, may not be necessary, allowing a program to avoid an overwhelming M&S effort and the associated deficiencies. Current M&S and testing tools are not advanced enough to accurately determine the engagement, encounter, and endgame conditions necessary to achieve such an assessment. Furthermore, a more thorough look at the most significant survivability factors in any pre-defined mission scenario would show that such a comprehensive assessment might be inefficient and limited to the conditions chosen. Rather, this concept eliminates the need to assess kill chain elements that do no significantly impact the final assessment and focuses on identifying and increasing the confidence of the evaluation of the most significant factors that affect survivability in realistic operational scenarios.

**Methodology**

Planning for a test and evaluation (T&E) program of any system should begin at the top level (Figure 1), with an understanding of the system, its critical components and functions, the operational deployment concept of the system, and its various mission scenarios. These might not always be complete early in the planning process, but they need to be understood by all evaluating organizations because they are critical in defining the common conditions under which the system will be assessed across the various acquisition stages. Otherwise, as similarly documented by the Defense Science Board and the National Academies, testing at disparate conditions could hide failure modes and performance limitations that will then adversely affect the evaluation later in the program and potentially the acquisition decision.
Intelligence information from system threat assessment reports and other capstone threat reports must also be evaluated to identify the expected threat types of concern, their capabilities, tactics, expected dispositions, and likelihood of encounter. These need to be coordinated across T&E organizations. Otherwise, assessing vulnerability and susceptibility at different encounter conditions will result in inadequate, individual data interfaces that prevent that data from being effectively combined into meaningful top-level survivability conclusions.

A practical ISA, proposed here, will determine how the critical threat capabilities, in the selected operational environments, might affect the performance of each critical attribute of the platform at risk (e.g. signature, countermeasures) and then the survivability of the same platform as a whole (e.g. effective employment against advanced threats). The threat kill chain, presented in Figure 2, can be used to help evaluate the survivability for the representative mission scenarios, but there should be no attempt to solve for each probability in the kill chain equation, since the probabilities are extremely dependent on the scenario chosen and the encounter, engagement, and endgame conditions associated with that scenario. The presented kill chain can be more finely resolved to reveal specific threat kill mechanisms and platform survivability enhancement or countering features.

Execution

In many cases, this kill chain, and the platform’s response to it, can be assessed by considering competing timelines: the threat timeline consisting of the time to recognize the threat and respond to it. Consider, for example, a hypothetical scenario in which an airborne intelligence, surveillance, and reconnaissance (ISR) aircraft without any installed countermeasures is targeted by a radio frequency (RF)-guided, surface-to-air missile (SAM) system as shown in Figure 3. With an understanding of threat system capabilities, it might be possible to concede that, if hit, the ISR aircraft would not survive (i.e., the threat is an overmatch). Survivability, in this case, will then depend on the strategies of knowing threat locations and avoiding engagements or of quickly detecting and identifying the threat and retreating beyond threat range before an intercept occurs. Survivability will be reliant on a fast threat warning capability that accurately identifies the threat and its location to prevent an intercept.

In this particular case, the ISA would focus on the competing timelines for threat targeting of the aircraft and for aircraft recognition of the threat and response. While intelligence sources provide the necessary threat performance data, the acquisition program will need to determine detection system response and accuracy, and aircraft aerodynamic performance for the retreat maneuver. The ISA strategy will identify the means required to make those determinations. For example, the competing timeline analysis, as shown in Figure 4, could use intelligence-based information for the threat in coordination with platform detection capabilities based on measured aircraft performance. From the kill chain perspective, the survivability assessment could, in this case, be focused on an assessment that carefully looks at selected kill chain time elements: the times for the threat to activate, detect, and track the aircraft, and launch and fly out to a hit versus the times for the aircraft to detect and identify the threat, and maneuver and escape outside the threat lethal range. Other aspects of survivability, traditionally captured by the kill chain, need not be addressed in this case because they...
rather than spreading them across the entire kill chain spectrum. Undeniably, this approach would not provide a quantified measure of survivability, but it would provide decision makers and soldiers with conclusions about the survivability of the system in its intended role, giving them a better understanding of the platform shortcomings and capabilities across the spectrum of missions in which it will be used. Additionally, the ISA could reveal areas that need further survivability enhancements. The assessment conclusions could be used to recommend whether other threat-tolerance or avoidance capabilities should be provided to improve the aircraft survival rate (e.g., in the hypothetical ISR aircraft scenario, installing RF countermeasures might need to be considered if the timelines show that aircraft cannot escape outside the threat lethal range by detection and maneuvering).

**ISA IMPLEMENTATION ISSUES**

**Coordination and Communication**

Efforts to assess various survivability elements fall under the responsibilities of different organizations. Some can be planned and tested independently of others, while others (e.g., countermeasures effectiveness and probability of hit) are closely related and would require cross-organizational interactions and coordination. A hypothetical example on the various survivability critical components and the responsible organizations is shown in Figure 5.

Recent programs have shown that test responsibilities and data needs that cross organizational lines are likely places where problems can occur (e.g., failure to plan for needed data or schedule effects that cause data to be generated too late to meet the needs of the other organizations). Legacy T&E practices include developmental testing (DT), operational testing (OT), and live fire testing (LFT) strategies that are formed independently of each other. Additionally, tests are frequently conducted in isolation from related M&S efforts. These are some of the historic barriers that threaten successful implementation of any ISA approach, including the one outlined here.

To avoid such problems, a clear framework for integrated assessments needs to be provided so that the guidelines for participation are clearly understood. Coordination and planning among DT, OT, and LFT&E, and between testers and modelers, are necessary at the beginning of the program to most effectively and comprehensively assess platform survivability. In all cases, the T&E organizations must coordinate their efforts to ensure that LFTs reflect the operational use of the aircraft and that DT data are adequate and timely to support both LFT&E and OT&E. Threats and scenarios must be consistent within the survivability assessment in order to adequately fold into each other to provide the most meaningful final assessment. Focusing on only the traditional scope of each organization’s assigned tasks and assuming that, in the end, all elements will come together is not likely to contribute to a successful approach.

**Established Guidelines**

To facilitate a feasible and successful ISA approach, the details of the approach need to be carefully planned and documented in the test and evaluation...
master plan, live fire strategy, and any DT-related document guides. The respective documents should reflect the coordination and communication needs, and should contain information that involves data transfer between the test organizations to ensure data needs are met. Continued emphasis on coordination will be needed and enforced throughout program execution by forming a Survivability Integrated Product Team, since schedule changes affect not only the acting organizations, but also those who are depending on the data they generate.

**CONCLUSION**

A practical ISA includes an assessment of the survivability of the aircraft against expected threats in the context of the missions it is flying. It focuses on a thorough study of the most significant elements critical to the system survivability in those missions. It does not involve an overwhelming M&S effort to provide the probability of survival calculations because such methodologies are currently not reliable and calculations of all kill chain elements might not even be necessary. Identifying the most critical factors that affect system survivability in any given scenario will eliminate the need to assess the elements of the kill chain that do not significantly affect the final assessment.

Specific tools to evaluate the most critical elements of survivability for the particular scenario have to be identified in the relevant test plan documents while ensuring an adequate interface between the various elements. The data needs and data transfers between the various test organizations and modelers must also be documented so that they can transpire in a timely manner. Activities from each organization involved must complement the others so that the resulting data can be successfully combined to reach over-arching, systematic and coordinated survivability conclusions that benefits both operators and decision makers.

The success of any joint initiative cannot be expected unless it is advantageous for all parties to participate. An ISA concept must be developed as early as possible in the development of the system, preferably during the analysis of alternatives, but certainly no later than Milestone B or the program entry point, if it enters post-Milestone B. The ISA concept must highlight the interdependency of all organizations involved and lay out a plan that coordinates T&E efforts among the program and services, DOT&E, AT&L, and their contractors to achieve an end-to-end assessment of the overall survivability of the aircraft in operationally representative scenarios to adequately inform aircraft operators and to support an acquisition decision.

**References**

[1] The notation “LFT&E Directed” or “OT&E Directed” refers to the primary oversight responsibilities within DOT&E.
EXCELLENCE IN SURVIVABILITY
DENNIS WILLIAMS

by Dale Atkinson

The Joint Aircraft Survivability Program (JASP) take great pleasure in recognizing Dennis Williams for Excellence in Survivability. Dennis has over 30 years of experience in the Operations Analysis Department at The Boeing Company, supporting aircraft survivability efforts. He has conducted survivability and vulnerability analyses to support Air Force Fighter competition proposals and progressed to managing the vulnerability engineering programs for the Advanced Tactical Fighter, F/A-18E/F, and EA-18G development programs.

Dennis is currently the technical lead for vulnerability engineering on the P-8A Multi-Mission Maritime Aircraft and KC-46 Aerial Refueling Development programs. In this position, he directs survivability and mission effectiveness analysis efforts in support of these military aircraft programs. He is a recognized expert in the field of survivability analysis and live fire testing, and is sought out to support key Boeing development programs and provide guidance where survivability of the design has been impacted.

Dennis has many career accomplishments, but one of the more noteworthy was his management and technical leadership of the Survivability Engineering Program for the EA-18G electronic attack aircraft developed for the Navy. Dennis led the analysis, demonstrating the high level of survivability of the design and its ability to meet specification requirements. Dennis worked with the Navy to develop program strategies to address the EA-18G design survivability critical issues using analysis and data from the earlier F/A-18E/F program. The results supported the decision to grant the EA-18G program approval to proceed into full rate production. Dennis feels his greatest accomplishment and personal satisfaction comes from knowing he contributed to improving the survivability of military platforms, which translates into saving the lives of our young men and women who fly aboard these aircraft.

Dennis graduated from Voorhees College in 1981 with a BS in mathematics. While working full-time with Boeing, he earned an MS in mathematics with an operations research concentration from Southern Illinois University in 1988. A member of the American Institute of Aeronautics and Astronautics, where he serves on the Technical Committee for Aircraft Survivability, he published a paper in the Joint Technical Coordinating Group on Aircraft Survivability Journal titled “Integrated Vulnerability and Product Safety Approach to Aircraft Survivability.” He was also featured in an article in the St. Louis American Newspaper titled, “Scientifically Speaking.” He has also written numerous technical reports for the Air Force and Navy as part of his job assignments.

Dennis actively mentors Boeing engineers and interns in professional career development, including providing letters of references for employment, graduate school, and for awards recognizing the accomplishments of engineers. He tutors high school students as part of Boeing’s cooperative effort with the National Urban League Business to School Event. Dennis has also volunteered his time for the Habitat for Humanity and Rebuilding Together program, where he helped build and repair homes for needy homeowners.
Dennis is married to the former Dorothy Rice, who he met while they were both students in mathematics at Voorhees College, and who is also employed by The Boeing Company’s IT Division. They have a son, Shawn, who is a student at University of Missouri.

It is with great pleasure that JASP honors Dennis Williams for his Excellence in Survivability contributions to the technical community, the Joint Aircraft Survivability Program Office, the Survivability discipline, and the soldier. [AS]
warfighting skills of senior Marine commanders and their staff prior to assuming command. In summary, the JCAT mission and its value to the Marine Corps remains confirmed as a value-enhancing capability to aviation soldiers.

A new project was initiated this year by USN JCAT—the development of a JCAT Training Range located at Naval Air Warfare Center Weapons Division (NAWCWD) China Lake, CA. China Lake has been the perennial training site for the JCAT Phase 2 class supported by the USN detachment at China Lake. Training is typically conducted using weapons damaged test aircraft that are parked in a fenced compound originally set up by the USAF JCAT group. This training has proven successful over the past 9 years and provides a good hands-on training experience for student JCAT assessors. A change in the training syllabus was introduced last year, which leveraged an actual F-4 crash site on the grounds of NAWCWD to provide a more realistic and challenging training experience. Based on the success of this exercise, the Officer in Charge of JCAT Det B CDR David Storr drew up a proposal and was granted 340 acres of China Lake range land to build a JCAT training range. The purpose of this range will be to stage realistic battle damage crash sites. The dimensions of the training range will allow for full size crash sites to be created, and the topography of the land will offer the possibility to stage notional firing positions related to the battle damage event, and will enhance realism and complexity of the training experience. Environmental and cultural surveys have been funded and are underway on the range. USN JCAT has an on-hand inventory of battle damaged test aircraft that can be used to populate the training range, and live fire tests are continually being conducted at NAWCWD, which should provide a steady stream of test articles for JCAT assessors to train on in the future.

During 2012, JCAT remained busy stateside as well. JCAT’s Army Component hosted the 2012 Threat Weapons and Effects Seminar at Eglin Air Force Base, FL, with almost 200 civilian and military personnel in attendance. This event demonstrated missile warhead effects against a transport category aircraft wing section and anti-tank guided missile damage to a static helicopter. Attendees included industry partners, six other US government agencies, and representatives from all US military Services.

JCAT also provides professional training to the US aviation community. The pre-deployment training provided in the US by the Army component touched 1,100 aircrew bound for combat duty and another 1,200 in professional military education courses and Department of Defense symposia. Overall, JCAT provided training and education to more than 5,700 personnel and recorded more than 2,700 downloads from their SIPRNET Knowledge Management sites. The JCAT mission enhances the Army Component’s tactics development duties as part of the Army Aviation Center of Excellence. This complementary role led to an additional 27,200 classified website downloads of JCAT and JCAT-influenced documents pertaining to threat determination and survivability subjects. In addition to the CONUS training provided by the Army Component, the USAF and USN forward-deployed assessors provide real-time training to deployed units in theater.
In recent years, the Pentagon’s Director for Live Fire Test and Evaluation (LFT&E) has placed a greater emphasis on passenger survivability from combat threats as part of LFT&E, and he has asked multi-Service participants in the Joint Aircraft Survivability Program (JASP) to explore models and technologies that evaluate and improve crew and passenger survivability. A closer examination of cabin safety improvement efforts (along with their underlying assumptions and limitations) underway at the Federal Aviation Administration (FAA) might lead to cooperation between the JASP and the FAA in JASP’s ongoing efforts to evaluate and improve combat survivability for military aircraft passengers.

The FAA classifies cabin safety into two distinct, but interrelated, categories: in-flight safety and post-crash survival. The primary focus of cabin safety is the safety and survivability of airplane occupants. FAA research activities aimed toward in-flight safety primarily address fire hazards, but also include other activities, such as protection against turbulence, decompression, and human factors design practices, to reduce and mitigate passenger injuries (e.g., no sharp edges or tripping hazards). Research activities aimed toward post-crash survival include crash (impact) protection, emergency evacuation, water landings, and post-evacuation survival, especially in harsh environments (e.g., fire, remote areas, water).

JASP divides aircraft combat survivability improvement efforts into susceptibility reduction (lowering the likelihood of aircraft taking a hit) and vulnerability reduction (lowering the likelihood of aircraft loss after taking a hit). [1,2] Of these, vulnerability reduction is more closely related to the issue of cabin safety, especially when applied to passenger survivability. Many of the strategies and technologies used to reduce aircraft vulnerability (redundancy, separation, active and passive fire suppression, etc.) are also used to increase aircraft safety.

The major differences between the safety and survivability disciplines lie in the nature and probability of the threat. The threats to cabin safety are related to aircraft and passenger hazards during normal operations, which are typically minimized through safety regulations and
policies. The risks are reduced by limiting hazardous conditions and improving the inherent reliability of components to stop those hazards once they occur. The hazard sources are, by nature, less intense and more unlikely than aircraft combat threats. Passive means (e.g., the use of fire retardant materials instead of automatic cabin fire suppression to defeat cabin fires) are often sufficient in civil aviation. Indeed, aircraft combat threats are designed to overcome the inherent safety features of an aircraft, and increase the probability of aircraft and passenger loss. Understanding the specific limits of military aircraft safety features (designed for peacetime used to be consistent with FAA regulations) might guide their application and improvement to reduce aircraft and passenger vulnerability to combat threats.

ANALOGOUS GOALS WITH DIFFERENT APPROACHES

The primary responsibility of the FAA’s in-house technical experts (at locations such as the William J. Hughes Technical Center near Atlantic City, NJ) is the development of reasonable safety standards and the test techniques to verify that these standards are met. It is up to the industry to develop technologies to meet those standards, using the test techniques developed by the FAA; however, in developing these standards, the FAA must thoroughly understand the “art of the possible,” and become heavily involved in the test of new technologies under development by industry, academia, and other areas of government. JASP’s own mission is similar, but emphasizes the development of needed survivability-enhancing technologies over the development of standards. Some areas of common interest between cabin safety and survivability communities are described in Figure 1.

JASP emphasizes the quantification of aircraft risk from combat threats as the basis for selecting the most promising technologies, and has just begun to extend those assessments to combat aircraft passenger injury risk. The FAA, on the other hand, uses the study of past accidents (and the identified sources of passenger casualties) as the primary basis for the establishment of new standards and technologies. [3] Although JASP has started to collect the potential sources for casualties in aircraft combat-related crashes within current theaters of operation, their efforts to study the causes of passenger casualties from past crash events are only just beginning. If military aircraft crashes caused by enemy threats are similar in casualty production to civilian airliner casualties, the FAA’s long record and deep understanding of past civilian accidents (crashes, hard landings, aircraft fires, etc.) could help JASP get a head start on developing passenger survivability technologies. These areas may include the use of fire retardant materials, fire and smoke sensors, emergency lighting, egress (door) designs, and in-cabin storage solutions (to speed egress and reduce blunt trauma) within passenger spaces.

TRAINING AND STANDARDS ARE PART OF THE SOLUTION

While the FAA studies civilian casualty production, with the basis of their standards possibly aiding JASP in identifying areas for reducing military aircraft passenger casualties following ballistic attack, it is possible that military casualty production is more sudden and severe than casualties produced in civilian airliner accidents. A deep understanding of the FAA’s assumptions made in establishing safety standards, including the intensity of civilian passenger hazards and the efficacy of existing equipment, could lead to needed enhancements of that equipment (or its rejection for use in military applications as “too little,” and not sufficiently weight effective for military application). It is also possible that “marginal” technical solutions that have not yet been implemented as standards by the FAA were rejected for reasons that would not necessarily apply to military aircraft passengers. For example, the FAA has so far rejected the widespread passenger use of gas hoods for reducing smoke-related casualties following a cabin fire, largely because of the difficulty in training a wide sector of the public in their use prior to each flight. Training of younger, warfighting passengers may be easier, and raise the utility of these technologies. It is also possible that the sources and intensity of smoke and fire in military aircraft cabins following ballistic attack could further justify their use (compared to civilian airliners).

The FAA has also had a very successful history of improving passenger survivability through the policies and regulations it has mandated on the civilian aerospace sector. The standards are often based on the extensive testing along with cost–benefits analysis with a metric of the number of lives saved. FAA economists evaluate the cost implications of the standards prior to any approval. JASP can leverage this experience of developing effective standards while the FAA can benefit from the live data that is often gathered by JASP in live fire demonstrations.

As important as technology is in reducing passenger casualties, improved training and operations can do as much or more to reduce passenger casualties following a crash or hard landing. In addition to the example of training for the use of gas hoods (above), the training for how best to egress a military aircraft following an
emergency landing is another example of how the FAA could enlighten existing practice. How often are soldiers trained to properly egress their aircraft in an emergency, considering the heavy personal equipment that they carry? Experience in the test of the Joint Cargo Aircraft in 2009 indicated that egress time of fully outfitted troops through a side door could decrease by 40% if the troops were told what to do with their equipment prior to egress. [4] What could further tests do to improve egress time? What would improved egress times mean to passenger survivability for aircraft? And, how could FAA experience help JASP answer these questions?

**KEY PARTNERSHIP DEVELOPMENT**

Recent technical exchanges between JASP and FAA technical representatives indicated a wide potential for future combined programs to improve safety and survivability, including:

- Test and evaluation of fire-resistant materials aboard combat aircraft
- Test and standards development for biofuel vulnerability
- Physics-based fire model development and validation testing
- Fire tests in explosive-resistant variable altitude chambers, including oxygen bottles, lithium batteries, and other hazardous aircraft components
- Test of aircraft wings or other components to transonic loads and fire hazards at altitudes up to 15,000 feet
- Test of pressurized (stressed skin) panels to catastrophic fracture under flaws (and potentially impact loading)
- Use of a variant of the recent JASP crew and passenger survivability models to quantify and improve civilian passenger safety
- Use of full scale, post-crash fire facilities for civilian and military aircraft

The areas highlighted represent only a fraction of FAA and JASP opportunities that were recently observed through meeting with FAA technical experts and touring the FAA William J. Hughes Technical Center. More opportunities for joint programs are likely to be uncovered at the FAA’s other facility at the Civil Aeromedical Institute in Oklahoma City, OK, which specializes in passenger cabin hazard level prediction, enclosure design, passenger tolerance levels, and egress testing and modeling. Given the tight fiscal restraints that all government agencies are facing, along with the commonalities described, JASP and the FAA should consider increased cooperation to improve each organization’s aircraft and occupant survivability programs along with the common usage of test facilities for both the civilian and military sector.

**References:**

[1] [http://www.aircraft survivability.com/Pages/Definitions.html](http://www.aircraft survivability.com/Pages/Definitions.html)


CREW COMPARTMENT FIRE SURVIVABILITY TESTING

by Patrick O’Connell and Adam Goss

Due to the many combat incidents involving helicopters during the Afghanistan and Iraq conflicts, the Director, Operational Test and Evaluation (DOT&E) and the aircraft vulnerability community has increased their efforts to assess and improve aircrew survivability. For the purpose of this article, the aircrew is defined as all air vehicle occupants to include the pilot, co-pilot, aircrew, and passengers. Historically, during vulnerability testing of aircraft, little attention was given to assessing the crew’s survivability. The crew was primarily addressed during vulnerability modeling and given the same importance as any other critical component on the aircraft. Today, more emphasis is placed on assessing crew vulnerability during testing, including assessing personnel injuries and fatalities related to direct hits, synergistic damage mechanisms, crash landings, or the inability of the crew to egress the aircraft after landing or crashing.

Vulnerability testing has shown that ballistic impacts of fuel and hydraulic lines can result in a sustained fire in the crew compartment; however, in these vulnerability tests, the fire was seldom allowed to burn for more than 10 to 15 seconds before being extinguished by test range firefighting equipment. The fire’s effect on the crew was usually not evaluated. To assess crew effects, the environment inside the crew compartment, from fire ignition to landing/egress, needs to be assessed for survivability.

While attempting to define the environment throughout a typical transport aircraft interior during threat-induced fire events, the parameters of temperature, air toxicity (oxygen [O₂] depletion and carbon monoxide [CO] concentration), and visual obscurity were selected as the primary environmental data to collect over time until certain criteria were reached, indicative of crew incapacitation or structural degradation of the platform. Quantifying the heat and CO environment was of particular interest as these have significant physiological implications. In general, when the CO concentration rises above 12,800 parts per million (ppm), immediate physiological effects, unconsciousness, and danger of death occur within 1 to 3 minutes. Also, as the air temperature approaches 203°C (397°F), the body starts to physically shut down the respiratory system, which can become irreversibly damaged.

This 3-year test program, accomplished from 2010–2012, was a collaborative effort between the Air Force (96 TG/OL-AC at Wright-Patterson Air Force Base, OH) and the Army (Army Research Laboratory’s Survivability/Lethality Analysis Directorate [ARL/SLAD] at Aberdeen Proving Ground, MD), and was sponsored by the Joint Live Fire (JLF) Aircraft program. Testing occurred at the Air Force’s Aerospace Vehicle Survivability Facility from March–July 2012.

OBJECTIVE

The primary test objective of this JLF program was to generate data necessary to evaluate crew vulnerability during a sustained aircraft compartment fire.

Data was collected to gather information required to answer the following overarching questions:

- How long does the crew compartment remain habitable if a fire occurs?
- Can the aircrew continue to perform their duties if a sustained fire occurs, and for how long?
- Could the aircraft crew safely egress upon landing with a fire aboard?

CREW COMPARTMENT FIRE TESTBED

An H-3 helicopter hulk, located at ARL/SLAD, was selected as the testbed for this program. The H-3 was a good candidate for the fire testbed primarily because its interior crew compartment is
large enough to represent a variety of fixed and rotary wing aircraft. In addition, the H-3 features two access points, a forward side door and an aft ramp, which can be used in future evaluations of different airflow configurations and to evaluate emergency egress options. Due to limited resources, the rotorcraft’s external doors, including the cargo ramp and windows, were all closed for this initial test; there was also no induced airflow, either externally or internally. Such aircraft configurations will be addressed in future testing.

To allow for repeated fire testing, modifications included making the floor and two test locations, one forward and one aft, more robust to withstand prolonged fire exposure. Steel fire pans, heat shields, and structural supports were installed to ensure that prolonged and repeated fire tests could be conducted (refer to Figure 1).

Further protective measures included an air evacuation system, an internal and external range firefighting carbon dioxide [CO2] system, and a water shower system. The evacuation system clears the interior of any toxic fumes or smoke by activating an exhaust fan mounted atop the structure, coupled with four motorized damper vents on the fuselage corners for fresh air intakes. CO2 nozzles were mounted around the aircraft exterior and throughout the interior, including the cabin cockpit and sub-floor dry bays, to extinguish sustained fires and cool the structure. Also, a 2-inch water pipe was positioned over the longitudinal centerline of the fuselage, and activated as a secondary measure to the CO2 system if skin temperatures reach an upper limit. The test fixture was designed so that it could be returned to a baseline configuration for each test.

Commercial off-the-shelf nozzles, designed for use in residential furnaces, were employed in conjunction with an aircraft igniter for repeatedly igniting controlled sprays of JP-8 fuel and hydraulic fluid (refer to Figure 2). Several sizes and types of these nozzles were pretested to select the most reliable units for igniting and sustaining fires. One small and one large hook-type nozzle were selected to represent small and large fluid line punctures from various sized threat impacts. Actual ballistic shots were unwarranted in this test since the objective concerned only the post-ignition fire environment. Use of these nozzles removed the inherent variability of ballistic shots, allowing for controlled, repeatable fire conditions. Follow-on testing will be accomplished to correlate the nozzle output with actual ballistic damage to fuel system components.

To quantify the environment inside the crew compartment during the progression of a fire, three different types of data were collected: temperature, O2, and CO gas concentration, and visual data. An instrumentation system was designed to collect this data consistently and accurately. Temperature time histories were collected from 103 thermocouples to obtain a temperature profile within the crew compartment throughout the fire duration. These sensors were mounted in 3x3 arrays (three ceiling level, three mid-height, and three floor level) at 10 different sections along the fuselage. Additional thermocouples included one each for the pilot and copilot, while other thermocouples monitored the H-3’s structure for hidden fires or heat damage.

Four pairs of O2 and CO sensors, capable of providing real-time concentration data, were mounted strategically throughout the testbed. One pair was positioned in the cockpit where the copilot’s head would be. Three other pairs of gas sensors were positioned in the passenger compartment, both at ceiling and floor level, as indicated in Figure 3.

Eight video cameras were installed throughout the cockpit and fuselage to provide complementary data to the temperature profiles and record the fire events, and also subsequent visual obscuration to fully understand what crew members would see during the fire. Visual obscuration for the pilot is assessed using a laser diode emitter and detector along with the pilot’s camera view (camera 2). The laser sensor and camera are co-located where the pilot’s head would be, and both are pointed at the instrument panel. Correlating the pilot camera with the change in the diode’s output can provide a quantitative
assessment to the pilot’s visibility over the course of a fire event. A decrease in diode’s output voltage corresponds to a decrease in visibility.

All instrumentation and test equipment on the testbed was controlled through LabView. LabView is a graphical user interface (GUI) that was developed to provide real-time test data and control during the test (refer to Figure 4). The indicators representing thermocouples change color according to the temperature scale at the bottom of the figure. To monitor exact temperatures on one of 10 rail sections, the desired section may be viewed in the exploded window near the tail of the fuselage. In the example provided, Rail Section 1 is selected with the maximum temperature at any given time, and is automatically outlined in red. The Cockpit and System Instrumentation windows monitor all other data, including gas concentrations, fluid temperatures and pressures, and the laser sensor. This program also provides a play-back feature of the test for post-processing.

Test fires were sustained until a condition indicative of aircrew incapacitation (pilot and co-pilot), aircraft loss (skin temperature above 900°F), or a total test time of 5 minutes was achieved. Specifically, aircrew incapacitation conditions consisted of a cockpit temperature above 400°F, a CO toxicity level above 12,800 ppm, or a depletion of O₂ to less than 12%.

TESTING ACCOMPLISHED

In total, 20 JP-8 tests were successfully accomplished, and 14 of 20 planned hydraulic tests were conducted. Six high-pressure hydraulic tests were skipped to preserve the test article structure due to rapidly escalating temperatures in these fires. Both the small and large nozzles were used in the test cases with the fuel being pressurized to 30, 65, and 100 pounds per square inch (psi) to represent a variety of aircraft types from helicopters to larger fixed-wing aircraft. The hydraulic fluid was tested at 50, 1,525, and 3,000 psi, representing both return and fully pressurized lines.

DATA ANALYSIS

All the numerical data collected for each test run was graphed to simplify analyzing the environment inside the crew compartment during the test fire and help answer the initial question of crew survivability. Thermocouple data was compiled into a series of graphs for each test to indicate the temperature profile at each of the 10 sections of the crew compartment and the cockpit. Toxicity plots that displayed O₂ depletion and CO accumulation were also generated for each test. Refer to Figure 6 and 7 for examples of these graphs. All together, these plots can be used to analyze the test environment throughout the crew compartment during an event.

Finally, video images inside the crew compartment during the test are provided alongside corresponding screen captures of the LabView GUI to correlate temperature and toxicity data with visibility.

A survivability assessment for the crew was accomplished for each test condition in the enclosed aircraft configuration. Survivability was defined as enough time for the aircrew to land the aircraft and to egress.

OBSERVATIONS

For JP-8 fires, the large nozzle, high-pressure condition appeared to be a threshold for survivability. Fire conditions at this threshold create a hazardous
environment in the crew compartment too quickly for personnel to react before reaching physiological limitations. Below this threshold, personnel have time to extinguish the fire before losing consciousness. Similarly, high pressure hydraulic conditions for both the small and large nozzles create hazardous environments that would not be survivable in this baseline aircraft configuration. Fires from low pressure hydraulic fluid are much less severe and self-extinguished in most cases. For sustained low pressure hydraulic fires, crew personnel would have ample time to extinguish them.

Overall, cockpit O₂ depletion is generally the first condition rendering the pilots incapacitated, which would lead to an aircraft loss. O₂ in the crew cabin followed the same depletion trend as in the cockpit, but with a faster rate near standing height and a slower rate near the floor. With the larger fires, O₂ depletion to below the 12% threshold can occur very quickly, and it is doubtful that a crew member could react fast enough to extinguish the fire. CO levels also climbed near dangerous levels in a few tests, but none of the tests were ended due to high CO levels. The small nozzle usually created fire events that were considered survivable by the aircrew, allowing enough time for them to land the aircraft and to egress.

The hydraulic fire tests produced more extreme events compared to the JP-8 fires and presented a significant threat to both personnel and the structural integrity of the aircraft. Future tests will be accomplished with hydraulic tubing to confirm that the intensity was not just the result of using a nozzle, but a result of the fluid burning properties.

The completely closed configuration of the testbed during the tests must be considered as a limitation to this assessment as effects of airflow or aircrew actions, such as opening the door or windows, were not measured factors.

CONCLUSION

This testing successfully achieved the objective set forth, providing initial data for completing a baseline assessment of aircrew vulnerability to fire, and also for establishing the foundation for future crew compartment fire survivability testing.

Further testing will be conducted this year to explore the effects of aircraft configuration and ventilation on the severity of crew compartment fires, and whether crew survivability can be improved by operational measures. Also, a detailed study will be conducted to determine the effectiveness of portable fire extinguishers currently found in most aircraft crew compartments. Advanced fire extinguishers, with either different dispensing technology or advanced extinguishing agents, will be evaluated.

Through the combined efforts of 96 TG and ARL/SLAD, this JLF program produced a solid foundation upon which future aircrew vulnerability assessments can be based. Results will lead to improvements in aircrew and air vehicle survivability.
CALENDAR OF EVENTS

APR

2013 The R&D ‘Use’ of Propulsion Vehicles  
2–4 April 2013  
Las Cruces, NM  

2013 Spring Simulation Multi-Conference  
7–10 April 2013  
San Diego, CA  
http://www.scs.org/springsim/2013

QUAD A Symposium  
10–13 April 2013  
Fort Worth, TX  

12th Annual 2013 C4ISR Journal Conference  
25–26 April 2013  
Arlington, VA  
http://c4isjournal.com/blogs/insider/registration

MAY

MODSIM World 2013  
1–2 May 2013  
Hampton, VA  
http://www.trainingsystems.org/events

Global Explosive Ordnance Disposal Conference and Exhibition  
1–2 May 2013  
Fort Walton Beach, FL  
http://www.ndia.org/meetings/3890/Pages/default.aspx

2013 SOFIC (Special Operations Forces Industry Conference)  
14–16 May 2013  
Tampa, FL  
http://www.ndia.org/meetings/3860/Pages/default.aspx

2013 Test Instrumentation: T&E on a Sustainment Budget  
14–17 May 2013  
Las Vegas, NV  
http://itea.org/index.php/share/conferences-and-workshops

AFCEA SOLUTIONS Series-George Mason University Symposium: “Critical Issues in C4I”  
21–22 May 2013  
Fairfax, VA  
http://www.afcea.org/events/gmu4i

Aircraft Combat Survivability Short Course  
21–24 May 2013  
Monterey, CA

JUN

2013 Joint Navigation Conference (JNC 2013)  
10–13 June 2013  
Orlando, FL  
http://www.ion.org/meetings/?conf=jnc&CFID=1797

5th Annual Soldier Equipment & Technology Expo & Conference  
18–20 June 2013  
Fort Bragg, NC  

National Live Fire Test & Evaluation Training & Technology Conference Event  
25–26 June 2013  
TBD  
http://application.ndia.org/abstracts/3390