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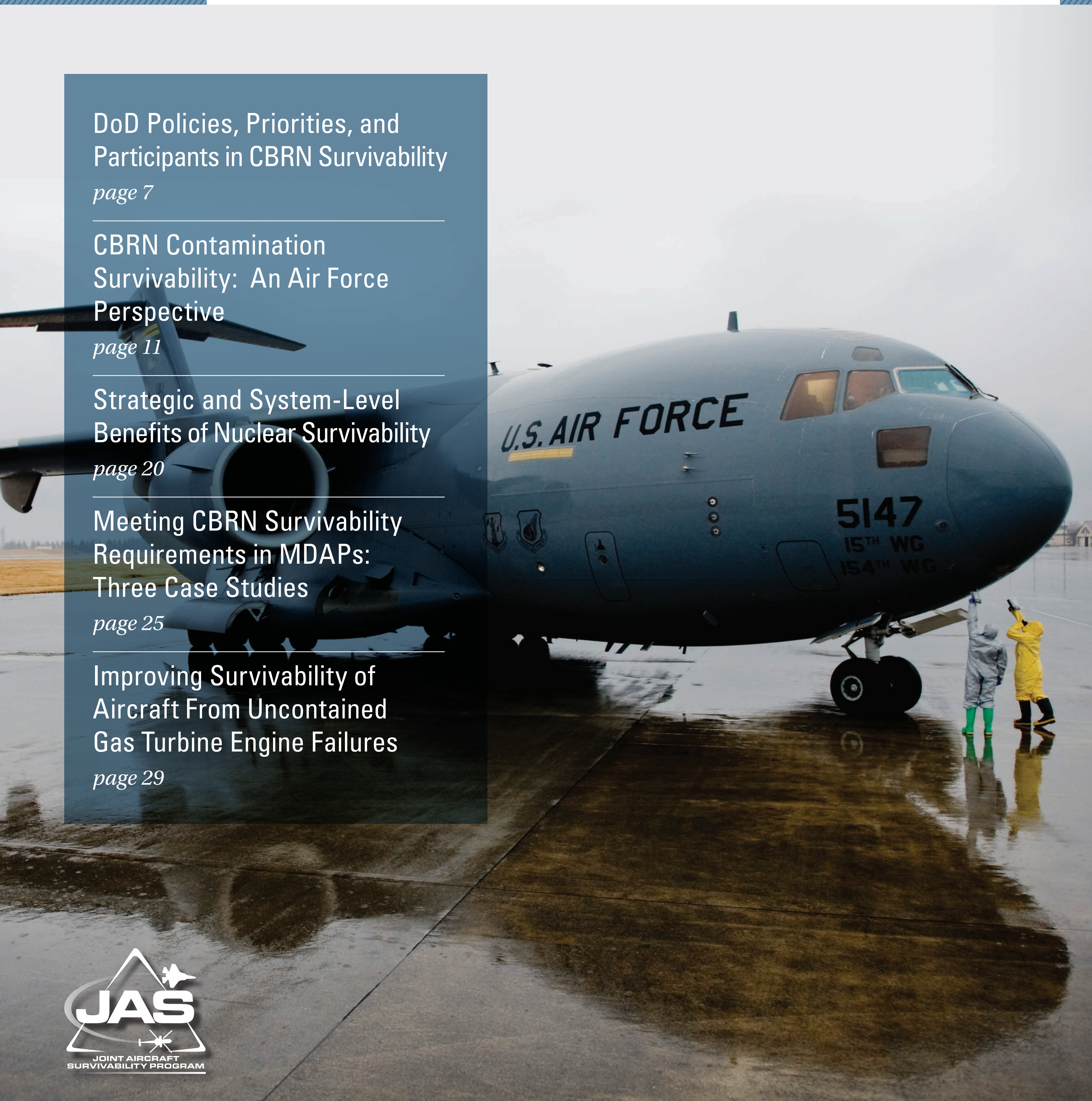

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On the cover:
Contamination Avoidance Team Scan for Possible Presence of Radiation Exposure on a C-17 Globemaster III at Yokota Air Base in Japan (U.S. Air Force Photo/SSgt Jonathan Steffen)

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The possibility that an adversary will use chemical, biological, radiological, and nuclear (CBRN) weapons or materials against the United States and its allies makes it increasingly important for a mission-critical system (MCS) to be able to survive such attacks. By definition, an MCS is a system (primary, auxiliary, or supporting) whose operational effectiveness and operational suitability are essential to successful mission completion or to aggregate residual combat capability. If this system fails, the mission likely will not be completed. A CBRN MCS is an MCS with operational concepts requiring employment and survivability in chemical, biological, and radiological (CBR) or nuclear environments. Accordingly, the primary objective of CBRN survivability is to enhance the protection of military systems, equipment, and facilities against CBRN threat environments and related weapons of mass destruction (WMD) to ensure that materiel used on the battlefield will survive a CBRN environment and that these systems and equipment can be operated by personnel in a protective posture.

Public Law (PL) 108-375 and the introduction of Department of Defense Instruction (DoDI) 3150.09 in 2008 set in motion far-reaching changes across the DoD to ensure mission-critical systems (MCSs) are survivable against chemical, biological, radiological, and nuclear (CBRN) contamination [1]. In turn, the Air Force established implementing policy and conducted Service-wide studies to confirm the capability of legacy MCSs, to ensure new systems address CBRN contamination survivability throughout their life cycle, and to take steps to strengthen capabilities going forward. The Air Force's CBRN survivability guidance, Air Force Instruction (AFI) 10-2607 [2], was published while Air Force experts conducted a systemic review focused on assessing CBRN survivability across all MCSs, documenting existing strengths, and identifying opportunities to bolster CBRN survivability.

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NEWS NOTES

By Dale Atkinson

2017 AIRCRAFT COMBAT SURVIVABILITY SHORT COURSE

In April, the Aircraft Combat Survivability (ASC) Short Course was held (for the first time) at the Air Force Institute of Technology (AFIT) at Wright-Patterson AFB (WPAFB), OH. More than 70 attendees and 16 instructors participated in this year's event, which was sponsored by the Joint Aircraft Survivability Program Office (JASPO) and supported by the Defense Systems Information Analysis Center (DSIAC).

The three-day course is based on the book *The Fundamentals of Aircraft Combat Survivability Analysis and Design* (second edition), written by long-time aircraft survivability instructor Dr. Robert Ball and published by the American Institute of Aerodynamics and Astrodynamics. The course is designed to provide an overview of the aircraft combat survivability discipline for government, military, and industry personnel working in survivability modeling and simulation, ballistic and vulnerability testing, susceptibility and vulnerability reduction, systems engineering, program management, acquisition, etc.

"This was the best ACS short course to date," said course organizer Professor Chris Adams of the Naval Postgraduate School. "AFIT provided a great location, as it allowed us to bring in several subject-matter experts from WPAFB."

The keynote lecture for the course was given by COL Sean Larkin, Commander of the National Air and Space Intelligence Center. Other course topics included:

- One-on-One Engagement, Mission, and Campaign Analyses
- Survivability Enhancements
- Integrated Survivability Assessment
- Combat Data
- Air Force Research Laboratory Laser Survivability
- Aircraft Survivability — Historical Perspective
- Joint Combat Assessment Team/ Aviation Shoot Down Assessment Team
- Current Threats Intel Brief, Surface-to-Air Fire Threats and Analysis
- Susceptibility and Aircraft Signatures
- Radar, Electronic Warfare, and Threat Operations
- Live Fire Test and Evaluation/Joint Live Fire
- High-Power Radio Frequency/ Directed-Energy Weapon Survivability
- Infrared Signatures and Countermeasures
- Threat Effects and Damage Processes
- Vulnerability Reduction Technology
- Critical Components and Vulnerability Assessment
- Force Protection and Recoverability
- Personnel Survivability and Human Systems Integration
- JASPO
- Large Transport Specific Aspects of Survivability, C17 Operations
- Helicopter-Specific Aspects of Survivability
- Fighter Operations and Survivability
- Aircraft Survivability Design and Optimization

In addition, attendees were given tours of the Dynamic Infrared Missile Evaluation (DIME) lab and the test range at Wright-Patterson AFB. For more information about the 2017 ASC Short Course or to inquire about next year's course (tentatively planned for April 2018), contact Chris Adams at caadams@nps.edu. ASJ

JCAT CORNER

by CDR Joseph Toth, CW5 R. Scott Brusuelas, LTC Arild Barrett, and CAPT Matthew Butkis

The past few months have involved a flurry of activity among the Joint Combat Assessment Team (JCAT). In April, JCAT travelled to Aberdeen Proving Ground, MD, to conduct a training assessment during Joint Live Fire (JLF) validation testing of foreign ammunition. A JCAT Army element, CW4 Bart Schmidt and CW3 Mike Clark, was joined by Navy JCAT members CDR Kevin Boissonneault and LTJG Dan Rolfe for this exercise. JCAT's mission of combat damage assessment requires team members to identify threats for the operational commander and collect combat damage data for survivability research and development. Over the course of 2 days, the team observed the JLF event and assessed the ammunition type and its effects on a rotary-wing platform. This hands-on training reinforces the skills necessary to conduct an assessment of combat damage by foreign weapons and strengthens the relationship JCAT has between its Service components and the test community. JCAT plans to sustain this type of training to remain prepared for deployment in support of the aviation community.

In addition, the Services have continued to build and train the JCAT membership across the Army, Navy, and Air Force. For more than a decade now, the three Services have made a dedicated effort to standardize and consolidate the training requirements used to prepare deploying JCAT members. JCAT officers take three phases of training prior to becoming certified. As mentioned in the spring 2017 issue of *Aircraft Survivability*, the Army component of JCAT conducted Phase 1 at Fort Rucker, AL, in January. A total of 25 personnel completed the week-long course of instruction, which focused on weapons and warhead effects, combat damage data collection, and casualty information collection.

In March, the Navy Component of JCAT hosted the week-long Phase 2 of the 2017 Joint Combat Assessor Training at the Naval Air Warfare Center in China Lake, CA (see Figure 1). The Phase 2 course is designed to build upon the student's Phase 1 training with additional classroom-based training of the JCAT mission, threat briefings, aircraft survivability equipment overviews, and hands-on training in actual data collection and threat assessment evaluation under simulated conditions. Navy LCDR Louis Miller facilitated this year's class, which trained 17 Air Force and Navy officers, as well as 1 civilian. Five Navy instructors, one Air Force instructor, and one Army instructor divided the students into four groups, with each group performing six assessments on a variety of aircraft platforms that had multiple demonstrated weapon system effects and in an environment closely resembling those of previous JCAT Iraq and Afghanistan

Figure 1 2017 Phase 2 Joint Combat Assessor Training Class

mobilizations. The aircraft "boneyard" and range are funded by the Joint Aircraft Survivability Program Office (JASPO) to properly maintain and improve a relatively large number of aircraft test articles used for assessment training.

In May, the Navy also hosted the Threat Weapon and Effects (TWE) Training Course at Hurlburt Field and Eglin AFB, near Fort Walton Beach, FL. This annual training event is a collaborative effort between the Joint Combat Assessment Team (sponsored by JASPO), the Army Research Laboratory, the Naval Air Systems Command, the Air Force Life Cycle Management Center, the Missile and Space Intelligence Center, the National Ground Intelligence Center, and other agencies. The training draws information from threat exploitation, live fire testing, and combat experience to provide a complete picture on threat lethality. Hands-on experience is provided with threat munitions/missiles, test articles, and damaged aircraft components. Experienced professionals provide current, relevant information on threat system upgrades, proliferation, and lethality.

Navy LCDR Calvin Martin orchestrated this year's event, which was attended by 122 aviation operations personnel, Intelligence professionals, weapons system developers, battle damage repair practitioners, survivability engineers, etc., from government and industry. This year's course was highlighted by presentations of combat resiliency, recent JCAT assessments, Russian air defense artillery, aircraft stealth design, and cyber effects on aircraft. This series of briefings provided key, timely topical insights germane to current military operations as well evolving areas of importance. As the aspects of world events and operations continue to change, it is essential that the team strives to anticipate the use of the latest threats and the impact to accomplishing its mission.

In addition to formal briefings, TWE course attendees were given a demonstration via the Dynamic in Terrorism (DIT) range conducted by the resident explosive ordnance disposal (EOD) team. This demonstration introduced the attendees to an overview of the DIT course and provided an awareness and appreciation of the organization, motivation, operational capabilities, and threats posed by terrorists on a regional, national, and international basis. Although the demonstration represented only a portion of the full course on terrorism/antiterrorism, it effectively emphasized this level of potential threats to U.S. forces and equipment as well as protective measures that government personnel and their families can employ to minimize the threat.

As is the case every year, the live fire demonstration at the Eglin range proved to be the highlight of the 3-day event. The first part of the demonstration illustrated the effects of hydrodynamic ram, with two 30-mm target practice rounds hitting two fuel tanks filled with water (simulating full aircraft fuel tanks). The "finale" centered around a UH-1 helicopter, first with a static shot involving a Stinger basic warhead and followed by a simulated suicide vest containing five pounds of C4. As a result of these successful live fires, attendees received a better understanding of threat dynamics and their effects on crew members and aircraft systems.

Along with the wrap-up of this year's JCAT courses, Air Force LTC Arild Barrett, a long-time JCAT instructor, wraps up 30 years of military service with his retirement on 1 July. "I have experienced about every status the Air Force has to offer," he recently said, "including dependent, Civil Air Patrol cadet, active duty, civilian employee, unit assigned reservist and [individual mobilization augmentee] (IMA) reservist. Now the only thing that is left is retire!"

LTC Barrett joined JCAT in 2012 after a long assignment with the A-10 System Program Office at Hill AFB, and serving the unit before that at McClellan and Beale. Following his active duty time as a B-52 navigator, he went on to continue his service in the Air Force Reserve as an intelligence officer with a C-5 squadron at Travis AFB. He later transferred to the IMA program as an aircraft structures engineer at McClellan AFB.

LTC Barrett noted that one of the capstone experiences of his career was deploying to Afghanistan on a short augmentation tour as a combat forensics evaluator in 2013. "It was the first time in my career that I was able to use my training in a real-world front lines operation," he said. "All my duty up to that point had been preparing to do a mission, but always in a training environment." He also said that he found the joint nature of the JCAT mission, working closely with the Navy and Army members, highly rewarding. LTC Barrett will continue to work his civilian job at Sikorsky Aircraft as a rotor systems engineer, and he also looks forward to having more time to pursuing his dream of completing a home-built airplane. ASJ

DoD POLICIES, PRIORITIES, AND PARTICIPANTS IN CBRN SURVIVABILITY

by Helen Mearns

U.S. Army Photo /SSG Ian Kummer

The possibility that an adversary will use chemical, biological, radiological, and nuclear (CBRN) weapons or materials against the United States and its allies makes it increasingly important for a mission-critical system (MCS) to be able to survive such attacks. By definition, an MCS is a system (primary, auxiliary, or supporting) whose operational effectiveness and operational suitability are essential to successful mission completion or to aggregate residual combat capability. If this system fails, the mission likely will not be completed. A CBRN MCS is an MCS with operational concepts requiring employment and survivability in chemical, biological, and radiological (CBR) or nuclear environments. Accordingly, the primary objective of CBRN survivability is to enhance the protection of military systems, equipment, and facilities against CBRN threat environments and related weapons of mass destruction (WMD) to ensure that materiel used on the battlefield will survive a CBRN environment and that these systems and equipment can be operated by personnel in a protective posture.

THE CBRN SURVIVABILITY POLICY

The issue of CBRN survivability is not new. In September 2008, the Department of Defense (DoD) issued DoD Instruction (DoDI) 3150.09, the CBRN Survivability Policy [1]. The policy, which was the culminating response to a series of reports and directives [2–6], defined CBRN MCSs and described how they are to be identified and reviewed to ensure their survivability in CBRN environments. The policy focused on the requirement that these systems be CBRN survivable in accordance with their capabilities documents' survivability requirements.

In April 2015, DoDI 3150.09 was reissued with an expanded scope to include deterrence. The policy now states that,

> *The force will be equipped to survive and operate in chemical, biological, and radiological (CBR) or nuclear environments as a deterrent to adversary use of weapons of mass destruction against the United States, its allies, and its interests.*

This distinction underlines the importance of CBRN survivability as an adversary deterrent, not just an acquisition mandate.

CBRN SURVIVABILITY DEFINED

CBRN survivability is the capability of a system to avoid, withstand, or operate during and after exposure to a CBRN environment (and decontamination process) without losing the ability to accomplish the assigned mission. Contamination here includes fallout and initial nuclear weapon effects, including blast, electromagnetic pulse (EMP), and other initial radiation and shockwave effects. All Acquisition Category 1 programs expected to operate in a CBR or nuclear environment are designated CBRN MCS and must be CBRN survivable in accordance with the applicable key performance parameters (KPPs).

CBRN survivability consists of two main aspects: CBR contamination survivability and nuclear survivability. *CBR contamination survivability* is the capability of a system and its crew to withstand a CBR-contaminated environment, including decontamination, without losing the ability to accomplish the assigned mission. Therefore, systems will probably maintain some functionality after being contaminated, but they may be severely degraded due to the deleterious effects of CBR substances, decontaminants, and decontamination processes if these are not considered in the design of the system. Additionally, protective equipment will need to be worn by the crew to operate the contaminated system, which will slow operations.

Nuclear survivability is the capability of a system or infrastructure to withstand exposure to nuclear environments without suffering the loss of ability to accomplish its designated mission throughout its life cycle.

As directed by the Defense Acquisition Board, each CBRN MCS under development as a DoD acquisition program must include in the Systems Engineering Plan how the design incorporates the CBRN survivability requirements and how progress toward these requirements is tracked and documented over the acquisition life cycle. Additionally, a legacy CBRN MCS undergoing requirements document review must also include CBRN threats, the CBRN mission-critical designation, and CBRN survivability in the requirements documents.

Achieving CBR contamination survivability is predicated on three principles: hardness, decontaminability, and compatibility.

CBR *hardness* is the capability of materiel or a system to withstand the damaging effects of CBR contamination and any decontaminants and procedures required to decontaminate it.

CBR *decontaminability* is the ability of a system to be rapidly and effectively decontaminated using standard decontaminants and procedures available in the field. Understandably, hardness and decontaminability are closely related. Achieving requirements in these areas is enhanced by using materials that do not absorb CBR contaminants and that facilitate their rapid removal and also by designing systems in such a way as to minimize or prevent the accumulation of CBR contaminants.

CBR *compatibility* refers to the ability of a system to be operated, maintained, and resupplied by personnel wearing the full individual protective equipment. Compatibility can be facilitated by designing systems that enable the ease of manipulation of controls when dexterity is hindered by wearing gloves.

Nuclear survivability may be accomplished by hardening, timely resupply, redundancy, mitigation techniques (including operational techniques), or any combination thereof and includes EMP survivability.

- Nuclear hardening is a design and manufacturing technique that allows the system to resist malfunction (temporary or permanent) and degraded performance induced by nuclear weapons effects. If the system is not protected, it will not function after a nuclear yield. Further, hardness maintenance and hardness surveillance procedures are required to ensure that the hardness built into a system is retained throughout its life cycle and not degraded through operational use, logistic support, or maintenance actions.

- Timely resupply is the fielding and positioning of extra systems or spares used for replacement of equipment lost to nuclear weapons effects.
- Redundancy is the incorporation of extra components into a system or the provision of alternate methods to accomplish a function so that if one fails, another is available.
- Mitigation techniques are used to reduce the vulnerability of a system to nuclear weapons effects through avoidance (to eliminate detection and attack), active defense (e.g., radar-jamming), and deception.

PARTICIPANTS AND PRIORITIES

Offices under the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD(AT&L)), the Secretaries of the Military Departments, the Joint Staff, and the Combatant Commanders have key roles with regard to the implementation of DoDI 3150.09. One aspect of these roles includes the preparation and review of the CBRN mission-critical reports (MCRs). The reports are used for managing CBRN survivability of programs and to enable senior-level oversight of the CBRN survivability posture across the DoD.

The Secretaries of the Military Departments and the Director of the Missile Defense Agency are responsible for submitting their respective CBRN MCRs and assessing the current survivability status of their CBRN MCS. Review and discussion of the CBRN MCR occurs at the CBRN Survivability Oversight Group meetings, which may be called by the Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense Programs; the Deputy Assistant Secretary of Defense for Chemical and Biological Defense (DASD(CBD)); or the Deputy Assistant Secretary of Defense for Nuclear Matters (DASD(NM)).

Additionally, the Joint CBRN Defense Program Analysis and Integration Office (PAIO), under the auspices of the office of the DASD(CBD), collaborates with the office of the DASD(NM) to review DoD CBRN Survivability Policy goals and progress in achieving those goals; monitor CBRN survivability research, development, test, and evaluation activities; and make recommendations to the USD(AT&L) or others as appropriate.

Based on lessons learned through implementation of DoDI 3150.09, the Joint CBRN Defense PAIO partnered with the Deputy Director, Operational Test & Evaluation (DOT&E)/Live Fire Test & Evaluation (LFT&E); the National Defense Industrial Association (NDIA) Combat Survivability Division; the Institute for Defense Analyses (IDA); and the Defense Threat Reduction Agency (DTRA) to co-sponsor one-day workshops for the aircraft community. In May 2014, a one-day workshop was presented on high-altitude EMP survivability of aircraft, followed in April 2015 by a one-day workshop on aircraft CBR contamination survivability. Each workshop provided a forum to address the CBRN threat posed to aircraft and, as a result, identified the need for more educational opportunities across the DoD.

Subsequently, the Joint CBRN Defense PAIO worked jointly with the offices of the DASD(CBD) and DASD(NM) to conduct a two-day DoD-sponsored CBRN Survivability Conference in November 2016. The conference, which was attended by approximately 100 participants, provided an opportunity for interaction between CBRN survivability subject-matter experts and those program executive offices and project managers who have a requirement for a system to be CBRN survivable but have little experience in the subject area. The conference included briefings by DoD organizations such as DTRA, the Joint Requirements Office, and the Joint Program Executive Office for Chemical and Biological Defense, as well as the Army, Navy, Air Force, U.S. Special Operations Command, and Maneuver Support Center of Excellence.

Conference topics included the following:

- An Introduction to DoDI 3150.09
- Operation Tomodachi
- Operational Perspective
- The Role of the Joint Combat Developer
- Support to Major Defense Acquisition Programs
- Service-Specific Briefs.

Two main themes emerged from the conference: requirements and training. The importance of integrating CBRN survivability requirements at the beginning of system development cannot be overemphasized. Additionally, as the DoD moves forward with implementing DoDI 3150.09, providing training to combat developers and materiel developers will be integral to successful implementation of the policy. Drs. David "Chris" Hassell (DASD(CBD)) and Vahid Majidi (DASD(NM)) also pressed the deterrent aspect of CBRN survivability. Survivability directly supports the U.S. approach to deterrence, a central concept to the nation's national security strategy.

CONCLUSION

The 2014 "Department of Defense Strategy for Countering Weapons of Mass Destruction" sums up the increasingly dangerous environment the United States faces when it comes to WMDs [7]:

> *Potential adversaries of the United States continue to pursue weapons of mass destruction (WMD) to enhance their international influence and achieve greater strategic leverage against U.S. advantages. Increased access to expertise, materials, and technologies heightens the risk that these adversaries will seek, acquire, proliferate, and employ WMD. Furthermore, instability in states pursuing or possessing WMD or related capabilities could lead to dangerous WMD crises.*

Accordingly, improving CBRN survivability of MCS is a key issue with profound implications for overall combat effectiveness of U.S. military forces. To be sure, the DoD has made great strides in, and focused much attention on, CBRN survivability, but there is still much work to be done. ASJ

ABOUT THE AUTHOR

Ms. Helen Mearns is currently the Deputy Director for the Chemical Security Analysis Center at the Department of Homeland Security. She has more than 25 years of experience in CBR contamination survivability. Previously, she worked for the Joint CBRN Defense PAIO, where she was responsible for oversight of technology objectives, engineering design standards, and test standards, supporting all aspects of research, development, test, and evaluation of CBRN defense equipment. She also served as the Principal Advisor to the DASD(CBD) on matters of CBRN survivability and managed the DoD CBRN Survivability Program in coordination with the office of the DASD(NM).

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CBRN CONTAMINATION SURVIVABILITY: AN AIR FORCE PERSPECTIVE

By William Greer, Jr.

Public Law (PL) 108-375 and the introduction of Department of Defense Instruction (DoDI) 3150.09 in 2008 set in motion far-reaching changes across the DoD to ensure mission-critical systems (MCSs) are survivable against chemical, biological, radiological, and nuclear (CBRN) contamination [1]. In turn, the Air Force established implementing policy and conducted Service-wide studies to confirm the capability of legacy MCSs, to ensure new systems address CBRN contamination survivability throughout their life cycle, and to take steps to strengthen capabilities going forward. The Air Force's CBRN survivability guidance, Air Force Instruction (AFI) 10-2607 [2], was published while Air Force experts conducted a systemic review focused on assessing CBRN survivability across all MCSs, documenting existing strengths, and identifying opportunities to bolster CBRN survivability.

Contamination Avoidance Team Scan for Possible Presence of Radiation Exposure on a C-17 Globemaster III at Yokota Air Base in Japan (U.S. Air Force Photo/SSgt Jonathan Steffen)


U.S. Marine Corps Photo

Today, the Air Force continues to improve CBRN survivability across its MCSs as well as work with the joint CBRN defense community on solutions to modernize and enhance total capability. This article briefly discusses CBRN survivability in the Air Force prior to PL 108-375 and DoDI 3150.09, the Air Force's CBRN survivability strategy for existing and new MCS, and several Air Force initiatives to bolster CBR contamination survivability and enhance mission capability as CBRN survivability evolves to meet changing CBRN threat environments.

MCS CBR contamination survivability involves a mix of three elements: hardness, human compatibility, and decontamination. Together, these elements constitute the parameters that define the criteria for quantifying a system's CBR contamination survivability capability. Finding the right balance to make a system suitably survivable, while achieving its required capability, requires assessing the system against CBRN threats in the context of its mission(s) and how well these three elements come together for the system to achieve a given contamination survivability capability. For both existing and new MCSs, CBRN survivability needs and the means to achieve a desired degree of CBRN survivability will change as threats evolve and CBRN survivability technologies improve. If an identified threat can degrade mission capability, or a system can otherwise benefit from improved CBRN survivability, further assessment will be needed to weigh the cost and benefit to enhance its survivability.

For example, any system can be absolutely CBRN survivable against all possible threats, well beyond what may ever manifest over the life of that system. However, the costs of added CBRN survivability—including impact on the acquisition life cycle; degradation of mission capability; cost to maintain; and impact on daily operability, maintainability, and reliability—must be weighed against the risks of operational effectiveness degradation or loss without improving one or more elements to enhance CBRN survivability capability. CBRN survivability is addressed in an ongoing process of MCS improvements to strengthen CBRN survivability capabilities over a system's life cycle along with looking to enhance agile combat support CBRN survivability capability within the Air Force.

Air Force and DoD CBRN survivability policies promote developing the right mix of CBRN survivability attributes in an MCS beginning at the earliest design phases, where a system developer can work to balance CBRN threats over the system service life and determine how each CBRN survivability element may factor into the operational design. The Air Force portfolio of existing MCSs includes numerous legacy systems developed years before enactment of PL 108-375, and developers did not always address CBRN survivability (as defined by DoDI 3150.09) during the acquisition phase. Attempting to determine what CBRN survivability was incorporated into legacy MCSs, while also ensuring CBRN survivability was addressed during the procurement of new systems, was an early task the Air Force set out to accomplish with the publication of AFI 10-2607. The Air Force is currently working to evolve both legacy and new MCSs so that Air Force-wide investments in MCS CBRN survivability capability continue to serve as an effective CBRN deterrent, as articulated in the current version of DoDI 3150.09.

HISTORIC FOUNDATION OF AIR FORCE CBRN CONTAMINATION SURVIVABILITY

Since World War I and the introduction of chemical weapons in modern warfare, each Service's approach for setting CBRN requirements was based on Service-specific capability needs in terms of developing required weapon system contamination survivability capabilities. This fact resulted in a mix of capabilities driven by Service-specific views on what was necessary to fight battles and win wars. Accordingly, the Army emphasis for years after World War I was on chemical warfare threats to land forces while the Navy focused on blue water threats to battle groups.

After World War II, the CBRN landscape changed as the United States and Soviet Union took on the roles of opposing superpowers, and the driving threat was the growth of nuclear weapons and intercontinental delivery systems. During this period, the Services, including the newly formed U.S. Air Force, worked to reshape themselves to counter the dominant CBRN threat: nuclear attack. This reshaping included developing new weapon systems able to survive long enough to deliver nuclear weapons to targets across the globe. During this time, nuclear effects and radioactive fallout, rather than chemical and biological (CB) threats, drove Air Force survivability.

As the Cold War continued, both the United States and the Soviet Union developed large inventories of nuclear weapons and amassed CB capabilities as part of the mix of offensive weaponry each side had stockpiled in the event the Cold War turned hot. Along with offensive capability being developed and procured, defensive capabilities were developed to make MCSs more CBRN survivable, although a good deal of this effort focused on items such as protective ensembles for personnel vs. altering or incorporating integrated CBR defense capabilities into MCS designs.

CBRN survivability during this period was treated as capability needed to defeat a Soviet/Warsaw Pact onslaught ending in total defeat of one side or the other; reconstituting post-global-war MCSs was not a priority. This was a logical approach, as MCSs employed materials that were not significantly degraded by sustained CBR exposure over the course of days or weeks (they were viewed as inherently hardened for CBR exposures) and the focus rested instead on protecting personnel over similar periods of days or weeks. While MCS decontamination was an integral part of training, it typically was focused on the immediate hazard and involved such practices as scrubbing exposed surfaces with hot soapy water that were intended to reduce hazards to levels allowing operations to continue (vs. restoring systems to unrestricted use among the general population).

During this time, CBRN requirements for various systems varied significantly as requirements and CBRN survivability options continued to evolve. Pre-DoDI 3150.09 baselines for systems CBRN survivability are still a factor in today's survivability because many legacy MCS designs were influenced by Service-specific contamination survivability assumptions. While their missions evolved along with the CBRN threat, their designs reflect, to some degree, their baseline CBRN survivability capability.

For example, for several decades after the U.S. Air Force was stood up, the primary CBRN threat was driven by the Cold War. As mentioned, nuclear and (potentially) radiological fallout drove CBRN (then often referred to as nuclear, biological, and chemical [NBC]) survivability, where either CB threats did not pose a major unique threat for Air Force weapon systems under original deployment scenarios or only one or two survivability elements were addressed in acquisition requirements and testing. Instead, systems were developed with inherently CBRN survivable materials mitigating impact, or it was often assumed that significant CBR contamination would lead to the MCS becoming a battlefield loss (equipment destroyed). As a result, some specific traits such as material compatibility were not necessarily tested in detail or verified in field trials.

Several techniques were developed to remove CBR, and while various methods were explored, procedures called out over the years in the various service manuals were "hot soapy water" and weathering. Both approaches were tested in recent years and found to not always clean complex weapon systems to the cleanliness levels expected today.

The post-World War II focus carried well into the 1990s, impacting how MCS developers addressed full CBRN survivability. Then emphasis was on two key CBRN survivability attributes: hardness and compatibility. Both were formulated to ensure MCSs could operate and execute missions through World War II-scale scenarios. However, when it came to restoring or recovering weapon systems, historical literature; field manuals (FMs); and tactics, techniques, and procedures (TTPs) for decontamination did not provide guidance to clear systems, suggesting the overall assumption was that contaminated systems would be abandoned or destroyed as no criteria were defined to fully restore weapon systems to unrestricted operations.

The 1993 version of FM 3-5, for example, speaks to immediate, operational, and thorough aircraft decontamination but emphasized avoidance as many decontamination methods were highly corrosive [3]. Clearance-level decontamination for aircraft was not addressed in the 1993 FM 3-5 version.

With the end of the Cold War, many MCSs were driven by a post-Soviet worldview, where weapons of mass destruction (WMD) were treated more as an isolated regional threat and not all systems required robust CBRN survivability capabilities. However, with the end of the Soviet Union and global initiatives to reduce CBRN weapon stockpiles worldwide, MCS CBRN survivability began to lose focus in the 1990s; and within a decade, concerns arose. These concerns were documented by the Government Accountability Office (GAO) in May 2003 (in GAO-03-325C) and again in April 2006 (in GAO-06-592) [4, 5]. Congress and the Bush Administration also focused on this concern under the October 2004 Ronald Reagan National Defense Act. These reports and legislation led to the DoD issuing DoDI 3150.09 in 2008.

DODI 3150.09 IMPACT ON AIR FORCE MCS CBRN SURVIVABILITY

Air Force MCSs come in many forms with capabilities to project force across a range of operational environments. CBRN threats that each MCS faces now and into the foreseeable future vary dramatically from system to system. Thus, assessing each system's contamination survivability capability must be framed and weighed against a mission-focused threat to ensure each has a level of survivability in line with a particular weapon system's mission. Within AFI 10-2607, processes are set forth to address CBRN survivability, the implementation of which is discussed in the following text.

AFPD 10-26 implements DoDI 3150.09 and (through AFI 10-2607) sets in motion initiatives to strengthen contamination survivability for both legacy and new MCSs [6]. Among the MCSs in the Air Force inventory, aircraft are the systems most likely to face major CBR threats. As such, aircraft contamination survivability is at the forefront of CBRN survivability work as the Air Force engages with the joint CB defense (CBD) community to develop new and innovative solutions to enhance MCS contamination survivability.

Table 1 lists some top-level attributes developers consider as new system designs mature. Realizing these types of attributes in aircraft designs requires an understanding of how the threat manifests; of existing capabilities employed operationally; of the ongoing progression of CBRN survivability initiatives; and, in turn, of developing approaches to improve the system's capability.

Implementation also calls for employing requirements analyses and systems engineering principles to all phases of the acquisition life-cycle process, as well as filling data gaps present in our understanding of contamination survivability and developing more robust operational capabilities.

CBRN is a threat collectively made up of quite divergent and unique threats. For much of Air Force MCS contamination survivability, the focus is on CBR. Nuclear survivability is concerned with prompt weapon effects associated with the immediate nuclear blast whereas CBR centers on the contamination resulting from CBR weapons, including radiological dispersal devices and low-level nuclear explosions.

Developing MCS solutions for chemical vs. radiological vs. biological contamination survivability does not lend itself to a one-size-fits-all approach. Instead, each must be considered independently (see probable aircraft exposure examples in Table 2). CBRN survivability requirements should be tailored so each system's incorporated contamination survivability is balanced to avoid excess requirements driving a design where CBRN survivability may come at the expense of other important performance requirements.

Table 1 Sample Contamination Survivability Considerations for Aircraft Systems

WEAPON SYSTEMS MUST BE CAPABLE OF:		
Operating in a C/B Environment (Fight Dirty)—Effectively Prosecute the War	Retaining Capability to Generate Sorties	Clearance Level Decontamination (Return to Normal Operations)
▶ Pilot and aircrew perform mission as well as ingress and egress • Aircrew protection during mission (air supply, eyes) ▶ Maintain in a full C/B protective posture (MOPP 4) • Equipment design • Spot/rapid decontamination	▶ Equipment survives for a specified duration (weeks) without maintenance due to C/B exposure in the threat environment	▶ Robust decontamination • Clean to level for unrestricted operations

Table 2 Typical Aircraft CBR Exposure Routes

ROUTE	CHARACTERISTIC
Liquid Chemical	▶ Can deposit on exposed exterior surfaces and enter portions of interior ▶ Droplets from weapon release ▶ Spray hitting landing gear bay/wheel wells ▶ Transfer from people/equipment being loaded ▶ Air vents and portions of the engine air intake (feeds environmental control system)
Vapor Chemical	▶ Can enter internal regions ▶ Any component or surface exposed to air is open for exposure
Biological (and Radiological)	▶ Can deposit on exterior surfaces and enter interior spaces, including inaccessible subsystems, such as heat exchangers and environmental control systems

For aircraft, where designers push materials to their limits to get the most out of every ounce of mass added to an airframe, chemical challenge is often the focus of developers for CBR vulnerability assessments. Exposure and its impact on materials must be understood in detail, as even a small degradation of material performance can have a significant impact. This understanding requires detailed studies, as CBR threats vary by agent and can manifest as both an immediate and long-term hazard and present as either a liquid or a vapor challenge. Biological and radiological threats generally present themselves as particles and have discrete properties that do not normally pose an immediate material hazard from an MCS vulnerability standpoint but may be problematic from an overall contamination survivability perspective.

For example, biological weapons typically do not show up in vulnerability studies of MCS hardness, as biological weapon organisms are selected because they are effective against people but have no history of quickly damaging materials normally employed in Air Force MCSs. However, when looking at all aspects of contamination survivability, focusing on both hardness against the threat and effective decontamination solutions presents a major contamination survivability challenge. Decontamination of anthrax spores, the most resilient form of *Bacillus anthracis*, is extremely difficult with aircraft. Many standard approaches employing sanitizing solutions such as chlorine can cause irreparable damage to some sensitive components in many Air Force MCSs.

As discussed, Air Force systems historically focused on biological threats as a "survivability afterthought" as they most generally did not pose a risk of mission failure while fighting a war. The question of recovering and returning aircraft to unrestricted operation was ignored; it was considered too difficult to warrant dedicating resources or would become someone else's problem after the fighting ended.

AFI 10-2607 AND CONTAMINATION SURVIVABILITY IN THE SYSTEM ACQUISITION PROCESS

CBR operational impact is MCS-specific, and understanding how each CBR threat can impact a given MCS enables incorporation of effective CBR contamination survivability into the MCS design process. As new system acquisitions take place, the CBRN survivability threat assessment is the analytic framework enabling the system developer to define CBRN survivability performance requirements the MCS should meet. Incorporating CBRN survivability into the systems engineering process allows designers to factor in various CBRN survivability strategies to meet defined performance requirements as the system design advances.

There are no prescriptive solutions to achieve CBRN survivability for MCSs. It is important to remember that for each Service, CBRN survivability requirements are driven by Service requirements and, within a Service, by mission needs. The Air Force has a variety of aircraft, both manned and unmanned, covering missions ranging from the nuclear enterprise and cyber security to acquisition, deployment, and operation of MCSs to support a multitude of users across the joint community.

Readers will recognize that CBRN survivability requirements for a cyber MCS will likely not be the same or employ the same solutions as those for space-based systems. Air Force CBR contamination survivability assessments reflect this reality; and as Air Force acquisition organizations implement DoDI 3150.09 and AFI 10-2607 requirements, they are working to balance cost, performance, and risk to get the best value. For systems at the greatest risk of CBR exposure, designers are employing systems engineering processes to develop end-to-end contamination survivability approaches.

As discussed previously, fundamental differences between threats call for assessments based on each threat's unique properties. Chemical threats present as vapor or liquid while biological and radiological threats generally present as particles. Whereas radiological particles create an ionizing radiation hazard, biological threats generally involve infection. The assessment of each CBR threat should draw on expertise that spans highly divergent fields of study, such as chemistry, physics, and biology. As developers delve deeper into the hazard impacts, other specialties, such as materials sciences, health physics, and toxicology may be required to understand how sensitive materials behave and how mitigation mechanisms in a design can limit personnel exposure during dirty operations.

For aircraft, where designers seek to maximize system performance, CBRN survivability approaches that add weight or degrade performance parameters will often be targeted in trade studies, potentially leading to reduced CBRN survivability capability and increased operational risk. Addressing CBRN survivability in the design often involves finding ways to harden the system and minimize contamination during exposure. Hardening the system though material selection is a crucial step in design resiliency against the threat, but that selection process should also factor in decontamination, as a treatment selected as an afterthought may be ineffective or be more destructive than the threat exposure in terms of potential system damage.

For MCSs such as aircraft, CBRN survivability is advancing on Air Force programs as developers formulate innovative approaches to satisfy system CBR contamination survivability requirements. A major step the Air Force has taken toward advancing comprehensive CBR contamination survivability is in system-level CB decontamination. Over the past 8 years, research and development has moved forward on system-level CB decontamination using only heat and controlled humidity, which are shown to inactivate biological threats and induce controlled accelerated weathering of residual chemical hazards (desorption).

Using the same underlining technology, two distinctly different decontamination mechanisms have been demonstrated both in the lab and in operationally representative field tests and demonstrations. As a result of this work and the effectiveness demonstrated to date, several new Air Force aircraft programs are adopting this technology by adding given parameters to the aircraft's performance requirements for CB decontamination. Air Force policy requiring developers to address CBR contamination survivability and, in particular, decontamination is taking hold in the acquisition offices' systems engineering processes. These acquisition programs are now working on the best approaches for implementing new decontamination methods within their designs when possible.

In turn, as this new approach gains momentum, joint agencies responsible for advancing the science, technology, and development of decontamination systems are investing to bring system-level operational decontamination capabilities to the Services. The Air Force is working closely with the Joint Program Executive Office for CB Defense (JPEO-CBD), the Joint Program Manager – Protection (JPM-P), and operational commands to field an operational capability, the Joint Biological Agent Decontamination System (JBADS), in the next several years.

For legacy systems, strengthening CBRN survivability is a challenge as the enhancements must be handled retroactively and conform to established design parameters. Fortunately, some mitigation actions are achievable as part of the sustainment process. For chemical threats, work on new, more effective coatings is advancing, and these coatings may also offer improved weapon system performance properties beyond reducing chemical agent absorption and contamination migration. Coatings that provide improved chemical warfare agent protection also tend to be more resistant to a wide range of chemicals that can affect a system over time, such as heavy air pollution, tropical humidity, salty air, and other contributors to long-term corrosion. In the case of aircraft, these coatings can also be beneficial by enhancing de-icing and reducing drag. These types of non-CBRN survivability cost benefits go a long way toward driving adoption of CBRN survivability enhancements in legacy systems as well as in new acquisitions as part of the overall systems engineering process.

In addition to approaches to harden the MCS through relatively simple changes, such as new coatings, joint research by the JPM-P program office and the Air Force Research laboratory (AFRL) (including lab and field tests) are showing promising results in the field of chemical decontamination. This work employs a hot air decontamination process that was identified early in the F-35 system design process. The approach works within the boundary of Air Force long-term storage temperature limits, a design envelop the Air Force employed for many legacy systems.

This long-term storage temperature limit was originally part of the F-35 airframe design, and testing to date shows promise in terms of controlled heat being safe to use on F-35 and meeting specified decontamination targets.

On the biological front, a similar method, JBADS, employs biothermal decontamination where the aircraft is heated (within the aircraft's long-term storage design limit), and controlled relative humidity creates a decontamination environment throughout the aircraft (Figure 1). JBADS was demonstrated in late 2014 during an Operational Utility Assessment (OUA) on a C-130H aircraft. Several tests confirmed JBADS effectively inactivated robust spore-forming organisms, such as *Bacillus thuringiensis* var. *kurstaki* (Btk), a hardy endospore that is as difficult to kill as its cousin *Bacillus anthracis*. Btk was selected as a simulant as it is environmentally safe and available commercially in the organic pest control section of many home and garden supply stores. A JBADS-based CB decontamination system was also used for the F-35 CB Live Fire tests beginning in late 2016 to verify the aircraft's biological decontamination capability.

The C-130H and the F-35, a legacy system and a new system, were treated to confirm effective biological decontamination employing the JBADS processes and confirm that each aircraft tested remained flyable after the treatment. While the C-130 and the first F-35 test aircraft were both removed from flight status prior to testing, maintenance inspections confirmed both systems were flyable. A second F-35 completed testing in March 2017 and returned to its home base after testing to verify the aircraft met its decontamination requirements. Results of the F-35 tests will be published later in 2017.

In addition to demonstrating decontamination, the JBADS approach also is moving beyond biological weapons and finding value in the Air Force as a novel tool to kill mold and mildew in aircraft. In the last 2 years, the JBADS processes were employed to treat various molds and mildews discovered under floor bays of an operational C-5B, in the forward and tail fuselage sections of an operational C-130 (see Figure 2), and most recently in a forward fuselage of an F-35. The treatments were effective, and the Air Force saved several million dollars over established hand-cleaning methods.

The dual-use approach leveraging contamination survivability technology was not originally planned, but JBADS developers—such as the AeroClave Corporation, which conducted the JBADS trials in 2014—found the opportunity to effectively employ JBADS technology to address non-WMD needs and show (through operational experience) that the processes are safe and effective for legacy systems, with no changes required to the aircraft.

These are a few examples of work underway by the Air Force and JPM-P to develop new decontamination capabilities that, while driven by limitations of sensitive materials and equipment on

Figure 1 C-130 JBADS Decontamination Enclosure Being Set Up for a 2014 OUA

Figure 2 Mold in the Galley (left) and Avionics (center) of a C-130 and the C-130 Interior Mold Treatment Underway (right)

aircraft, can also be employed by other Services, federal agencies, and organizations interested in decontamination where these processes can meet biological mitigation/remediation needs. JBADS does not address some Service rapid decontamination requirements, as the processes take several days and are intended to support decontamination needs of MCSs with sensitive materials and equipment. Users with suitably hard equipment or weapon systems may choose other approaches (designed to decontaminate in minutes or hours) as a preferred solution when speed is a priority. Air Force leaders agree that removing an aircraft from operations after hostilities subside for a few days or weeks to restore it to normal unrestricted operations is much preferred to rapid decontamination treatments that may permanently degrade or risk loss of each contaminated aircraft.

EXAMPLES OF OTHER COLLABORATIVE AIR FORCE AND JOINT CONTAMINATION SURVIVABILITY INITIATIVES

Along with implementing policy, assessing current capabilities, developing more robust CBRN survivability requirements, and embedding CBRN survivability into the systems engineering process for new systems (and for upgrading legacy systems), the Air Force is working with both the JPEO-CBD community and the Defense Threat Reduction Agency (DTRA) to advance CBRN survivability technologies. Over the past 2 decades, the Air Force has undertaken several initiatives to improve CBRN survivability, spanning development of innovative TTPs to enhance operations in dirty environments, and has invested in CBRN survivability across MCSs.

Studies have included research on chemical agent fate to explore alternate TTPs to reduce hazard exposure. These studies, which have led to implementing Split Mission-Oriented Protective Posture (Split MOPP) to facilitate restoring airbase operations, have been incorporated in Air Force Manual (AFMAN) 10-2602. However, while Split MOPP has helped to reduce the burden of airman continually wearing MOPP gear on a base with dirty zones, it has not prevented hazard exposure and has meant that equipment, including MCSs exposed to chemical agents, needed to be decontaminated.

Studies performed by DTRA and the Air Force explored several approaches to decontaminate systems, and from that work, AFRL embarked on developing system-level decontamination, employing heated air to desorb and induce accelerated weathering to reduce hazards without harming aircraft (as discussed previously). In conjunction with tackling chemical decontamination with hot air, AFRL also explored other biological decontamination potential approaches. Based on those studies, AFRL focused research on heated air combined with controlled humidity to achieve biological decontamination.

This research has made major strides in a few short years as AFRL led the JBADS Joint Capability Technology Demonstration (JCTD), which helped advance system-level biological decontamination to a Technology Readiness Level 7 through tests performed using a C-130H. With the success of the JBADS JCTD, further testing was conducted, and the JBADS process was selected for the F-35's biological decontamination. A second prototype CB decontamination system was then developed by JPM-P for the F-35 Live Fire Test, combining these two methods.

Related Air Force CBRN survivability research initiatives are also showing promise. AFRL research has produced a new coating dubbed "Diamondback" that shows some promise in resisting chemical absorption, and it is undergoing long-term environmental tests as a CBR contamination survivability coating to mitigate contamination and help with de-icing and in-flight drag. Other studies over the past decade have centered on more foundational research evaluating the properties of materials exposed to chemical hazards as well as some decontamination systems. This research explored and quantified material properties and compatibility for numerous MCS materials to identify degradation due to agent exposure as well as degradation risks possible from some decontamination solutions. This research is ongoing, and as materials are assessed, AFRL is publishing results to materials databases to promulgate what is learned so system developers can access and be informed on material effects and, in turn, improve their system's CBR hardness.

This year also saw AFRL along with Navy researchers kick off studies to quantify the effects of ocular exposure to chemical agents. This research will help to answer questions about the exposure risks to aircrew and the ability of aircrews and other warfighters to perform mission-critical operations if low-level exposure manifests as ocular meiosis, which can, for example, degrade aircrew performance.

These initiatives have spanned both material and nonmaterial solutions. This work will help to advance CBRN survivability for MCSs as the Air Force looks at ways to limit exposure, operate more effectively when MCS is contaminated, and develop/adopt technologies to mitigate hazards. These advances may allow the Services to balance material and nonmaterial options and operate dirty, knowing their MCS capabilities are not being significantly degraded. And when the time comes, the Services can reconstitute the forces and warfighting assets and employ effective decontamination methods to restore MCS to full operations.

CLOSING THOUGHTS

Since the signing of PL 108-375 and its implementation through DoDI 3150.09 and AFI 10-2607, the law's impact continues to reverberate within the Air Force. Surveys were done to assess the state of MCSs across the Air Force, and steps were taken to bring a balanced contamination survivability capability to MCSs and strengthen contamination survivability capability through multiple avenues. These avenues have included evolving concepts of operations (CONOPs) and TTPs, embedding contamination survivability in the systems engineering process of systems identified to be CB survivable, developing technology solutions, and engaging with the joint CB defense community. Furthermore, studies have identified opportunities and needs to help the Air Force invest and grow CBRN survivability capability through a mix of material and nonmaterial options.

Implementation is ongoing, and a good deal is being accomplished today. Within the Air Force CBRN community, however, there is still much to do to embed the right mix of CBR contamination survivability capabilities into MCSs to meet mission needs. This accomplishment will not happen overnight, but those practitioners working in these issues are seeing positive trends as they strive to strengthen the Air Force's ability to ensure MCSs survive any known and future CBRN threats as the Air Force carries out its global mission. ASJ

ABOUT THE AUTHOR

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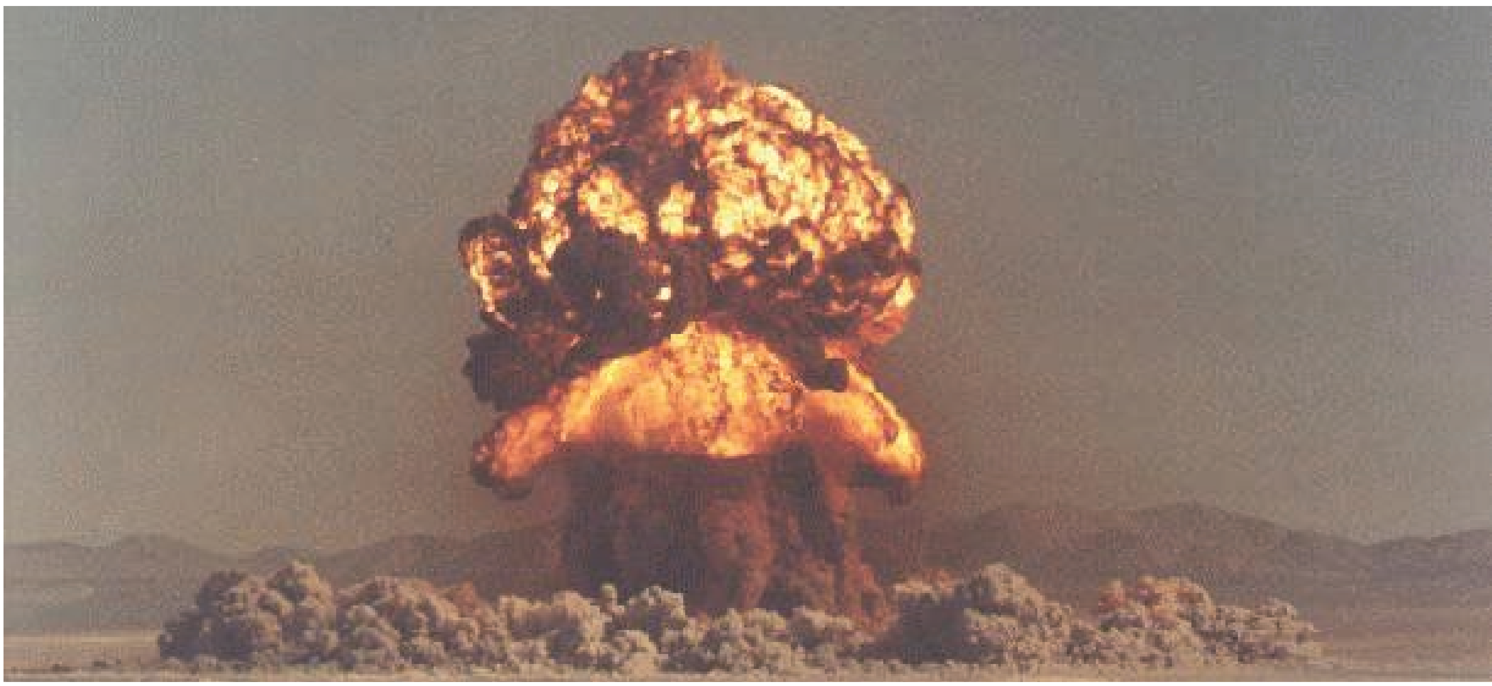
STRATEGIC AND SYSTEM-LEVEL BENEFITS OF NUCLEAR SURVIVABILITY

by Nick Haugen and Mark Diglio



(Editor's Note: This article is an update to an article published in the Combating WMD Journal*, issue 8, winter/spring 2012.)*

The Army has prepared itself to face nuclear threats since it built and used the world's first nuclear weapons in combat. Today, the Army requires that all mission-critical systems with electronics be hardened against the nuclear weapon effect of a high-altitude electromagnetic pulse (HEMP) [1]. The HEMP survivability requirement is generally not challenged by combat and material developers. From a threat standpoint, a HEMP can be created by a nation or state with relatively undeveloped nuclear and missile technology. A single nuclear weapon detonated at high altitude can generate a HEMP over a wide area [2]. In terms of hardening, dealing with HEMP is not unlike dealing with other electromagnetic environmental effects (E3), such as lightning, directed-energy weapons, and interference from friendly communications emitters and radars. If one is dealing with a set of E3, adding HEMP to the set earlier in the design is not costly or technologically challenging.

The Army also requires that mission-critical weapons systems be hardened against a broader set of nuclear weapons effects [1]. This requirement is more frequently resisted by developers. The nuclear threat is a less obvious threat than most traditional threats (because few states have tactical nuclear weapons) and is more difficult to harden against.

With the demise of the Soviet Union, there were no clear-cut scenarios involving the use of nuclear weapons against deployed formations. However, the future holds a resurgent Russia with claims upon the Arctic Ocean's resources and Russian-speaking former Soviet Republics, as well as a nuclear-modernizing China with claims upon the South China Sea. Considering Russia's substantial tactical nuclear weapons arsenal, the prospects of limited regional nuclear conflict are real [3]. When one does imagine a nuclear weapon being used against our forces, it is easier to imagine a response involving the United States responding in-kind than continuing the conventional fight on the battlefield.

In addition to nuclear threats being less obvious, the hardening against nuclear effects as an afterthought can be daunting. One must deal with thermal radiation, nuclear blast, and initial nuclear radiation (INR). The INR environment is composed of neutrons and gamma rays, considering both dose rate and total dose, which affect electronics in different ways. Most major combat systems are full of vulnerable advanced computer technologies. Added to these challenges is the increasing pressure to save money in the face of significant and ongoing budget cuts.

This article discusses both the strategic and individual program-level benefits of the Army's requirement to harden mission-critical systems against thermal radiation, nuclear blast, INR, and EMP with an eye to promote the same in Air Force systems. For example, dual-use-capable aircraft (such as the F-35 shown in Figure 1) need protection against EMP nuclear effects.

Figure 1 F-35A Lightning II Aircraft (U.S. Air Force Photo/SSgt Madelyn Brown)

STRATEGIC BENEFITS

The benefits to the Army's nuclear hardness program extend beyond the survivability of individual systems. By sustaining the Army's nuclear survivability program, we dissuade adversary proliferation, sustain the technical knowledge associated with nuclear hardening, and assure mission capability for regional nuclear conflicts. These strategic benefits exist independent of a single system's capability. The key is maintaining these nuclear hardening requirements for enough systems through the life-cycle maintenance process to realize these strategic benefits for sustained nuclear environment mission capability. Nuclear survivability capability is critical for most aircraft and their supporting systems.

To dissuade adversary proliferation, we must influence a potential nuclear weapon state's decision on whether or not to develop or otherwise acquire nuclear weapons. (This understanding of dissuasion, distinct from deterrence, as influencing how an adversary competes, is from M. Elaine Bunn [4].) A state's violating a promise not to proliferate can cause significant costs, such as international sanctions or military intervention (as with Syria and North Korea). Both imposing costs and denying benefits are important elements. If a proliferating state is a potential adversary of the United States—a likely case—then it will see less benefit to possessing nuclear weapons if it knows that U.S. forces are fully prepared to deal with nuclear weapons (credibility). If we field forces that are hardened to the effects of nuclear weapons, there is one less benefit to an adversary obtaining them. On the other hand, if we abandon our hardening program, we present the potential enemy with a softer target, giving that enemy one more weight on the scale in his calculation of whether or not to obtain or use nuclear weapons.

One could argue that the hardness of U.S. Army combat systems is not likely to be a significant driver in this decision. If one considers Iraq's on-and-off weapons program prior to 2003, it is difficult to imagine Saddam Hussein carefully considering whether or not to develop nuclear weapons on the basis of whether or not the Abrams tank was hardened. However, suppose that the U.S. Army had abandoned its policy of hardening its systems against nuclear weapons. Instead of thinking of the specific hardness level of a specific weapon, Saddam might have more generally concluded that the U.S. military was vulnerable to nuclear weapons and/or was too afraid (or otherwise unwilling) to deal with these weapons." Hypothetically, this conclusion would have been rational and could have been a significant factor in his decision regarding nuclear weapons development (though more likely averting nuclear weapons possession would serve Saddam as a deterrent from attacking neighbors).

The second strategic benefit of nuclear survivability is sustaining the technical knowledge base. The Army has been able to attract talented engineers and scientists to commit to a career based on knowledge of nuclear weapons effects. This technical knowledge base can be compared to a human body. It is mature and healthy. Its health can be sustained through modest effort and expense. If we allow it to die, however, it would be extremely difficult to replace it with an infant. Even worse, we cannot know when or for what purpose we will need this knowledge base. The Army would face a situation similar to that faced by the Air Force and Navy, which have not sustained the expertise necessary to maintain their strategic ballistic missiles to the point that, according to the Defense Science Board, "current skills may not be able to cope with unanticipated failures requiring analysis, testing, and redesign [5]."

By maintaining the nuclear hardness requirement and consistently applying it, we create a need for material developers who understand the impact of nuclear weapons effects on systems and the technical approaches for addressing those impacts. In addition, we create a need for combat developers to understand how nuclear weapons impact the forces they are developing. We also create the need for parts suppliers to build radiation-tolerant parts. Finally, we sustain our test facilities and their personnel.

As with dissuading adversary proliferation, rational arguments exist against maintaining the technical knowledge base. One could read through the list of aforementioned professionals who need to maintain nuclear knowledge and think that the investment could hardly be worth the cost. In addition, conventional thought might suggest that cutting this initiative is a chance to accept a bit of risk and spend taxpayers' money on something more pressing. This thought might be true were it not for the modest cost of the Army's hardening program (such as with the Bradley Fighting Vehicles in Figure 2).

Historically, acquiring and sustaining a system's nuclear hardness amount to about 1% of a program's total life-cycle costs. And when one considers the defense budget and the fact that not all systems require full nuclear survivability, this cost is relatively cheap.

For comparison, consider how much the Army spends on big-ticket programs that are cancelled prior to production. How much do they contribute to our long-term security? Implementing modest spending cuts to wasteful programs, incorporating nuclear survivability, and sustaining funding are cheap ways to mitigate long-term operational mission risks.

Certainly, similar opportunities for survivability capability must exist for critical Air Force systems too.

INDIVIDUAL PROGRAM BENEFITS

As noble a goal as achieving these strategic benefits might be, the Army spends money program by program. The weight then falls to the individual Program Manager (PM) who must justify his program costs and the Milestone Decision Authority (MDA) to decide the priority of funded capabilities. The PM might not be able to "take one for the team" and have his nuclear survivability program contribute a wide range of strategic survivability benefits. Instead, he will likely need something specific and relevant to his individual system to justify any costs. Fortunately, there are concrete benefits to an individual program and the Warfighters who use the system.

The most important of these benefits is the preparedness against future threats. In their recent study of ground vehicle

Figure 2 Bradley M2A3s Arriving in Korea, Hardened to Survive Nuclear Weapons Effects at Modest Cost to the Army (Photo Credit: Glen Curtis)

modernization in the U.S. Army and Marine Corps, Andrew Krepinevich and Eric Lindsey of the Center for Strategic and Budgetary Assessments identify the proliferation of nuclear weapons as one of seven trends impacting the future land warfare environment. They find that [6]:

> *The ongoing proliferation of nuclear weapons and changing attitudes about their use will substantially increase the likelihood that U.S. military forces will confront an adversary that is willing and able to employ nuclear weapons.*

Besides noting the increasing likelihood of a nuclear battlefield in the developing world, Krepinevich and Lindsey cite a published Central Intelligence Agency memorandum and congressional testimony that point to Russian development of small-yield nuclear weapons (such as the one being testing in Figure 3) and more flexible employment doctrine [6].

One might challenge the relevance of this assessment when discussing the Abrams and Bradley, as these are cases of matching legacy systems against hypothetical future threats. However, the Abrams and Bradley vehicles will be in service another 20 years. Consider that more than 25 years ago, Russia was a threat in its incarnation as the Soviet Union. Although that threat subsided, it has already resurfaced as an even more complex threat. Who will guarantee that Russia does not use the tactical part of its 12,000 nuclear warheads or that these weapons will remain tightly secured and controlled [7]?

Furthermore, many other weapons of mass destruction (WMD)-capable adversaries might the United States need to deal with in the next 25 years? If our relationship with Russia can change so dramatically in one 25-year period, can it not change again in the next 25 years with other adversaries? Per General Mark Milley, Chief of Staff of the Army, the five growing WMD threats today are Russia, China, North Korea, Iran, and violently radical terrorist organizations [3]. Since 1999, Russia's strategic doctrine subscribes to a policy known as "escalate to deescalate." This strategy describes a scenario of first use-limited nuclear strikes, for example, to get NATO and the United States to back down from any regional or local confrontations or preemptively in situations critical to national security [8, 9]. With Russia and China expanding territorial claims today and irrational belligerence from rogue states, nuclear survivability is an increasingly relevant requirement for all mission-critical systems and many of their subsystems.

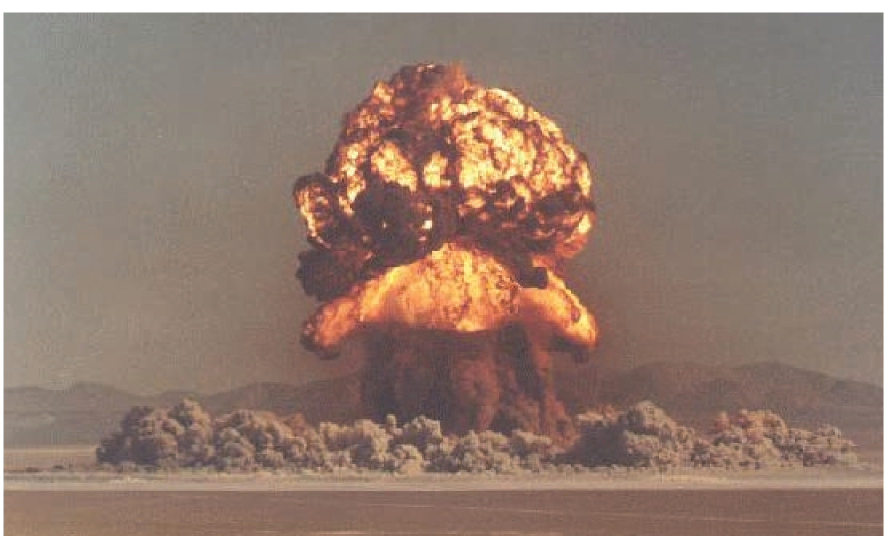


Figure 3 The Small 11-kt Fizeau Nuclear Test at the Nevada Test Site, September 1957 (Trinity Atomic Web Site)

Another benefit to an individual program is that, by sustaining a system's nuclear hardness, it is much less expensive than trying to recreate it. Just as the Army's survivability knowledge as a whole is inexpensively maintained—it cannot be easily or quickly recreated—the same holds true with the hardness of an individual system. Currently, the essential parts of a hardened vehicle are tested on a supplier-by-supplier basis, the results are captured in a database, fixes for faulty parts are implemented, and faulty parts are tracked through the fleet of fielded systems, etc.

In the case of the Abrams and Bradley, this management system has been developed and improved over 35 years. Once abandoned, the knowledge of which parts from which suppliers are inherently hard, of how to fix faulty parts, of what parts are in what vehicles, of how to manage the databases that track this information, and of how to test parts for radiation tolerance will surely wither away and die. Surely the cost of recreating this system is an order of magnitude higher than simply sustaining it. And even if today's user does not want nuclear-hardened vehicles or aircraft, what about the user 10 or 15 years from now? If one justifies a modest savings by sacrificing survivability hardening for today's user, one is setting up the future user for significant cost growth and even likely failure of meeting future needs.

A third system-level benefit is that hardened systems deter enemy nuclear weapon use. Just as a hardening program throughout the Army impacts an adversary's decision on whether to develop nuclear weapons, a survivable formation impacts his decision to use them. In this case, the benefit is much more concrete. The impact of nuclear weapons on battlefield formations can be modeled with confidence. Currently, the Army hardens its systems to the level at which humans will survive on the battlefield. If we stop hardening our systems, the radius at which our formations are likely to be impacted by a nuclear weapon extends from the radius at which humans in vehicles are inherently vulnerable to the level at which electronics are disrupted. In extremely rough terms, this leads to a quadrupling of the area impacted. If an enemy can quadruple the area over which his nuclear weapon is effective, he is that much more likely to use it.

A final system-level benefit of sustaining a full Army nuclear hardening program deals with soldier morale. Currently, combat vehicles are designed and built so that if the crew members live, their vehicle works. The consistent message communicated to them is, "After the event, keep fighting," and "If you live, you still have a mission [10]." However, lowering the level at which we harden vehicles complicates and sours this message. If some or all functions are left unhardened, the message to operators would more likely be something like, "After the event, get your vehicle as close to the rally point as possible before you collapse so that we can repair it and give it to another crew," or "If the automotive system works but the fire control system does not, you likely will not be with us much longer." Applying this concept specifically to aircraft (whether parked on the ground or flying in the air), an aircraft's ability to operate "after the flash" is critical. Even a low-yield, high-altitude nuclear pop can fry unprotected computer, communications, sensors, and control equipment; and the post-attack time is the time when a system is needed most. And trying to add nuclear protection after a system is fielded could prove to be an insurmountable effort and impractical for adding any usable survivability capability.

CONCLUSION

The U.S. military is facing tough decisions in the near future on how to accomplish its mission with a smaller budget. Naturally, all of the DoD spending needs to be examined to ensure that we are not wasting increasingly scarce resources. However, leaders need to make decisions on nuclear survivability with their eyes wide open. And any decision today to cut a nuclear hardening program will present a significant challenge for future decision-makers as the nuclear weapons threat becomes increasingly more serious and real. ASJ

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Mr. Mark Diglio has served as the Army's CBRN Survivability Manager at USCANA since 2016. Previously, he was the Associate Project Manager for the Program Manager for Chemical Demilitarization, and he developed and managed Army CBRN filtration and detection systems at Aberdeen Proving Ground, MD. Mr. Diglio holds a B.S. in chemical engineering from the Pennsylvania State University, an M.B.A. from the Florida Institute of Technology, and an M.S. in CWMD defense strategic studies from Missouri State University.

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MEETING CBRN SURVIVABILITY REQUIREMENTS IN MDAPs: THREE CASE STUDIES

by John Lazerlere and Brant Lagoon

U.S. Army Photo/SGT Josephine Carlson

Each Major Defense Acquisition Program (MDAP) is responsible for meeting its chemical, biological, radiological, and nuclear (CBRN) survivability requirements. However, addressing CBRN survivability is not intuitive. There are material, operational, logistical, integrational, interoperability, functional, and life-cycle requirements that must be assessed and addressed. And if not addressed properly, any one of these can cause programmatic hurdles that can increase cost and slow a program down.

In an effort to help MDAPs walk this minefield, the Department of Defense (DoD) issued DoD Instruction (DoDI) 3150.09, titled "The Chemical, Biological, Radiological, and Nuclear (CBRN) Survivability Policy," in September 2008 [1]. As discussed elsewhere in this issue, DoDI 3150.09 states,

> *The ability of the force to operate in these environments must be known and assessed on a regular basis, and Mission Critical Systems (MCS) that must survive and operate in CBR environments, nuclear environments, or combined CBRN environments will be specified.*

In addition, all Acquisition Category 1 programs expected to operate in a CBRN environment "are designated CBRN MCS and must be CBRN survivable in accordance with the applicable key performance parameters (KPPs)."

This instruction not only defined the term MCS but further outlined how such systems are identified and reviewed to ensure CBRN survivability in accordance with their survivability requirements. An MCS is any system that, if it were to fail or become a casualty, would severely degrade the probability of mission success. In April of 2015, DoDI 3150.09 was updated and reissued to include deterrence, noting that, "The force will be equipped to survive and operate in CBR or nuclear environments as a deterrent to adversary use of weapons of mass destruction [2]."

Established by Congress through the National Defense Authorization Act, Public Law 102-160, the Joint Program Executive Office for Chemical and Biological Defense (JPEO-CBD) is the principal advocate and single point of contact for all research, development, acquisition, fielding, and life-cycle support of CBRN Defense equipment and medical countermeasures. The JPEO-CBD established the MDAP CBR Survivability Support Team (SST) as the single point of contact to integrate CBRN Defense capabilities into MDAPs. The MDAP CBR SST concept supports the execution of DoDI 3150.09 and ensures consistent integration of CBRN capabilities across the Services by:

- Building partnerships for the integration of technology.
- Building consensus for major governance and acquisition decisions.
- Being responsible for horizontal integration across the enterprise.

Since January 2011, the MDAP CBR SST function resides within the office of the Joint Project Manager for Protection (JPM P)—one of five JPMs within the JPEO-CBD. The mission of the MDAP CBR SST is to serve as the primary interface between MDAPs and the JPEO-CBD and ensure that CBRN Defense capability requirements are adequately addressed in a way that minimizes redundancy of effort across the DoD and improves platform CBRN survivability efficiently.

The MDAP support process (illustrated in Figure 1) includes numerous services and products that the MDAP CBR SST can deliver, including but not limited to the following:

- Providing CBRN subject-matter expert (SME) support.
- Performing systems engineering analyses to develop CBRN-specific operational and technical requirements and/or developing recommended CBRN-specific requirements for inclusion in the program's Capability Development Document and/or the Capability Production Document.
- Performing systems engineering analyses to identify existing CBRN materiel solutions to best meet documented requirements.
- Identifying performance gaps between existing materiel and technical requirements.
- Developing cost and schedule estimates to align CBRN requirements with the system-of-systems acquisition strategy.
- Helping to develop tactics, techniques, and procedures (TTPs) to address identified gaps.
- Identifying, assessing, and tracking risks.
- Conducting preliminary CBRN test and evaluation (T&E) and logistics planning.
- Developing CBRN Defense architectures products.
- Performing trade space analyses to optimize CBRN survivability capabilities within cost and schedule constraints.

Over the years, the JPM P has assisted programs at various stages in their acquisition life cycle. The following three aviation/aircraft-related programs are examples of how the JPM P has worked with MDAPs in using/modifying

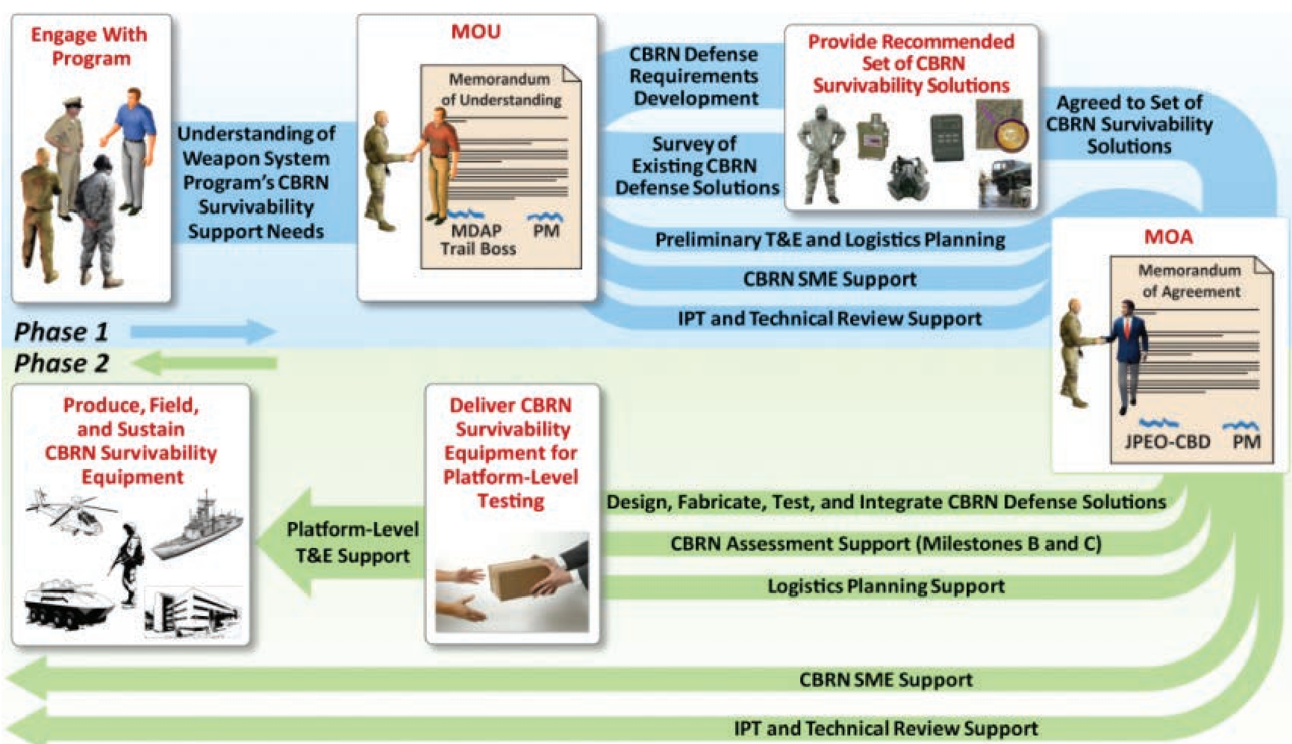

Figure 1 MDAP Support Process

an existing CBRN Program of Record (PoR), establishing a new CBRN PoR, and demonstrating new CBRN capabilities/technologies.

JOINT SERVICE AIRCREW MASK-JOINT STRIKE FIGHTER (JSAM-JSF)

Using/modifying an existing CBRN PoR is one way MDAPs can capitalize on existing CBRN Defense systems and hardware. Tasked with addressing overarching chemical and biological (CB) contamination survivability and CB Defense requirements, the JSF Program Office (PO) coordinated with JPEO-CBD (becoming the first program with a live fire test requirement to do so). One of the solution sets for meeting CBR survivability was the use of the JSAM. When integrated with aircraft-mounted and pilot-mounted equipment, the JSAM-JSF (shown in Figure 2) will provide combined (simultaneous as required) hypoxia, CB, and gravity-induced loss of consciousness protection.

As part of this effort, the MDAP CBR SST was involved in establishing the Memorandum of Agreement (MOA) between the JSF PO and the JPEO-CBD. The MOA defined the roles and responsibilities of each party. This agreement was key for allowing the development of the mask prior to the January 2017 JSF CB Live Fire Test and Evaluation (LFT&E).

Figure 2 JSAM-JSF

JOINT BIOLOGICAL AGENT DECONTAMINATION SYSTEM (JBADS)

In some cases, there may not be a CBRN PoR to turn to in order to meet CBRN survivability requirements. Establishing a new CBRN PoR may be the best course of action, and the MDAP CBR SST, working through the JPEO-CBD, may recommend the establishment of a new program. The JBADS program was established from such a need. The JBADS is an acquisition program to meet DoD needs for decontamination of aircraft against biological warfare agents and other biological agents of concern. The initial JBADS will focus on a biological decontamination capability for the C-130 aircraft. The JBADS will be a capability set that includes an aircraft enclosure and decontamination units that provide hot, humid air (biothermal decontamination) to decontaminate biologically contaminated airframes to a minimum 6-log reduction level.

An aircraft biological decontamination capability was demonstrated under the JBADS Joint Capability Technology Demonstration (JCTD) in 2014. The MDAP SST Lead for Aircraft was designated as the Transition Officer between the JCTD and a potential PoR. As such, the MDAP SST was involved in reviewing the designs and provided funds to accomplish the JCTD. In addition, the MDAP SST reviewed the JCTD Operational Assessment Report and incorporated it, along with the Capability Development Document and the Lessons Learned, into the Performance Specification for the PoR.

The MDAP SST assisted the Joint Science and Technology Office in setup and scheduling and participated in a Technology Readiness Assessment (TRA) based on the JCTD results and prior testing of biothermal decontamination in FY15. Based on the TRA assigning JBADS a Technology Readiness Level (TRL) of 7, the JBADS entered the acquisition life cycle at Milestone B as of 9 May 2017. Development of the JBADS has the potential to impact future PoRs that are planned to address chemical decontamination capabilities and to decontaminate tactical platforms as determined by the Services.

JSF DECONTAMINATION SYSTEM

As programs work toward meeting their CBRN survivability requirements, there may be a need for a new capability. Such was the case for the JSF decontamination system (illustrated in Figure 3). From the onset, JSF employed a systems engineering approach to CBR contamination survivability. The JSF PO

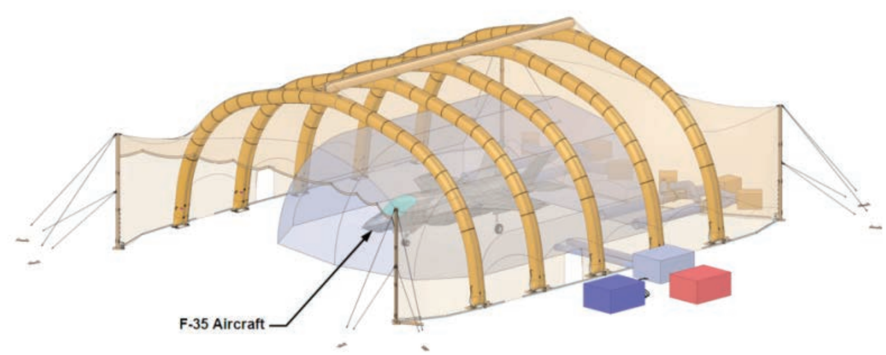

Figure 3 JSF Notional Decontamination System

and the Air Force Research Laboratory (AFRL) performed a battery of tests and demonstrations, including material (coupon) testing. F-35 chemical hardness risk reduction verification tests were conducted to determine the efficacy of structural heating/forced hot air for interior chemical decontamination. To verify biological hardness for interior biological agent decontaminability, the JSF PO and AFRL conducted risk reduction verification tests using vaporized hydrogen peroxide (VHP). VHP testing was also conducted on materials exposed to live agent to assess material compatibility, off-gassing, contact hazard, physical property testing, and special property tests. This information helped establish physical properties data needs.

All of this pointed to the need for a hot air decontamination system for the F-35 aircraft. Working through the JPEO-CBD, the MDAP CBR SST and the JSF PO collaborated on a successful design, integration, and test of a CB decontamination system for the F-35. In support of the JSF F-35 CB Survivability System-Level Qualification, LFT&E (#CB-06), the JPM P and AFRL developed and demonstrated a prototype decontamination system. The decontamination system is designed to provide required temperature conditions inside a protective shelter/containment liner system for required timeframes. The CB LFT&E was completed during the second quarter of FY17.

Through coordination early on in the acquisition process, the MDAP CBR SST can ensure that CBRN Defense capability requirements are adequately addressed in a way that minimizes redundancy of effort across the DoD throughout the life cycle of the platform. This process prevents duplication of effort, assists programs in achieving their CBRN survivability requirements, increases interoperability among the various platforms, and affirms that CBRN Defense systems are sustainable throughout the life of the platform.

MDAPs can also benefit from existing expertise and technical reachback that the MDAP CBR SST can provide. The team can help direct MDAPs to existing material solutions and serve as the gateway into CBD Program solutions. The team regularly interfaces with a network of technical experts in research, testing, evaluation, analysis, hardware development, engineering, integration, fielding, logistics, and many other areas. In addition, it routinely works with organizations within the DoD, academia, and private industry. This interaction can help take the burden and guesswork out of knowing how to meet program CBRN survivability requirements from program initiation through life-cycle management planning. Early involvement with the MDAP CBR SST is key to providing CBRN survivability with the best cost/benefit and least impact to program execution.

For further information or to receive assistance for facilitating research development, testing, procurement, operations and sustainment, and delivery of CBRN Defense systems in support of platforms designated CBRN mission-critical, as well as those requiring CBRN Defense capabilities, please contact the JPEO-CBD Public Affairs office at 703-617-2400 or usarmy.apg.jpeo-cbd.mbx.jpeo-cbd-public-affairs-office@mail.mil. ASJ

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Mr. John Larzelere currently serves as the MDAP Platform CBR Survivability Lead for Ships and Buildings. He has 30 years of experience in basic research, equipment and hardware design and development, program management, and personnel management. This experience includes supporting the Marine Corps Operational Test and Evaluation Activity as the Early Test and Evaluation Lead. He also spent 6 months in Afghanistan supporting the Joint Expeditionary Forensics Facilities and the Security Force Advisory and Assistance Team, as well as 4 months in Japan supporting Operation Tomodachi. In addition, Mr. Larzelere has conducted research on filtration technologies and holds a patent in fan rotor design. He has a B.S. in mechanical engineering from North Carolina State University.

Mr. Brant Lagoon is currently the MDAP Platform CBR Survivability Lead for Aircraft and Transportable Systems. He is the Systems Engineering Lead for the Joint Biological Agent Decontamination System. He has worked in chemical and biological protection systems for 15 years, beginning as an active duty Air Force Project Manager for collective protection systems. After working with protection and filtration system in industry for several years, he became a physical scientist for the U.S. Army Natick Soldier Research Development and Engineering Center. Mr. Lagoon holds a mathematics degree from the University of St. Thomas.

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IMPROVING SURVIVABILITY OF AIRCRAFT FROM UNCONTAINED GAS TURBINE ENGINE FAILURES

by Chris Adams and John Manion

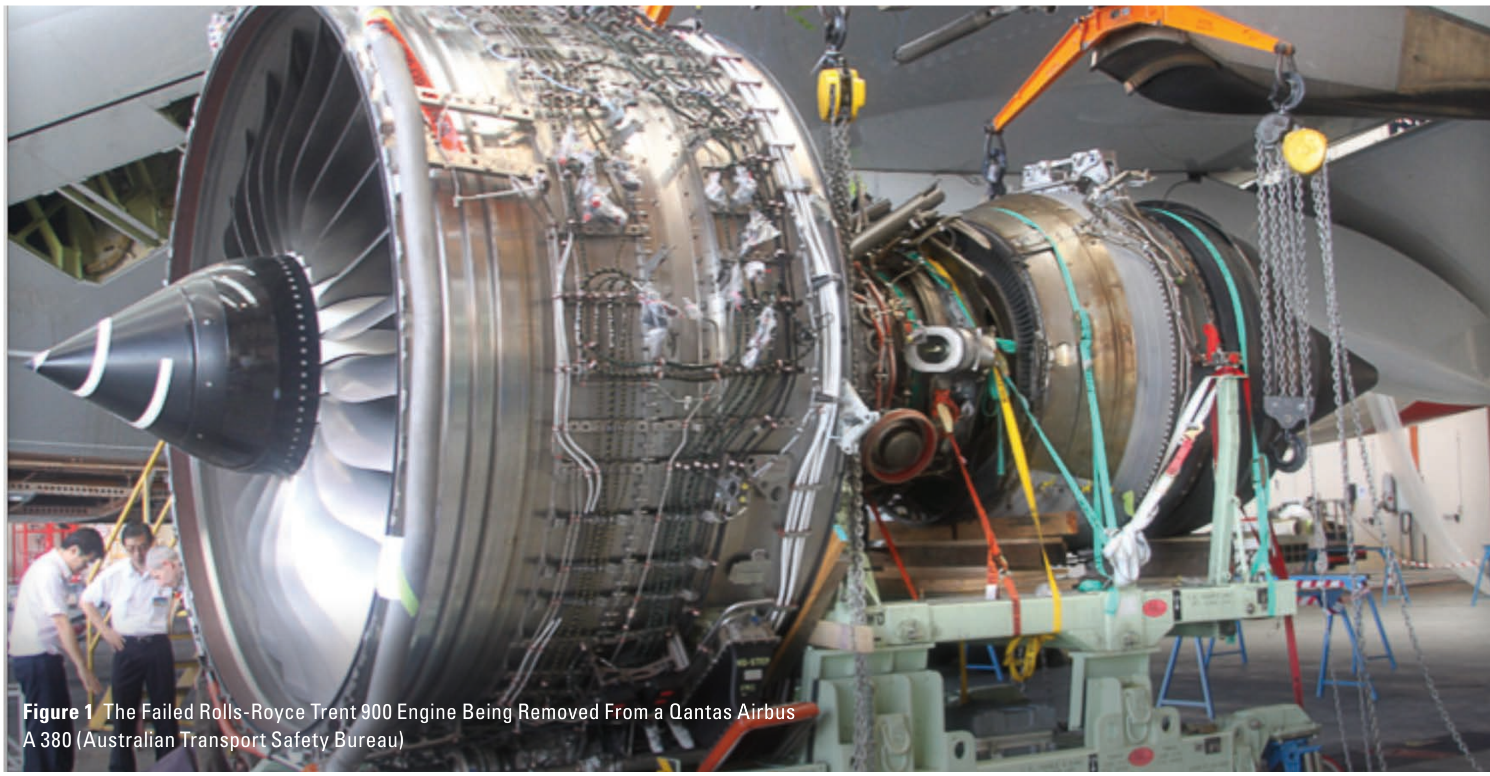

Figure 1 The Failed Rolls-Royce Trent 900 Engine Being Removed From a Qantas Airbus A 380 (Australian Transport Safety Bureau)

Modern, high-bypass ratio aircraft gas turbines used in commercial aviation and on military transports have an exceptionally high level of reliability; however, events do occur that lead to catastrophic engine failures. While typically the engine is destroyed in such events, it is desired to fully contain any debris and not have a fire that spreads. Occasionally, an engine will suffer an uncontained engine debris event. Most engines are required to meet a specific level of debris containment, but more severe events can and do occur, such as the 4 November 2010 incident of Qantas flight 32 (an Airbus A380 aircraft with Rolls-Royce Trent 900 series engines) (see Figure 1). The number 2 engine sustained an uncontained failure of the intermediate pressure (IP) turbine disc soon after takeoff from Changi Airport, Singapore, for Sydney, Australia.

Commercial airplane manufacturers are required by both the U.S. Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA) to certify that their designs are able to meet stringent requirements of flight safety in case of a catastrophic event. Recent military aircraft programs, using specific military designs and commercial derivatives, have also required certification similar to FAA and EASA requirements.

Although the design safety requirements are now essentially the same for commercial and military aircraft, there currently is no standard methodology for certifying the safety of the aircraft in the event of a hazardous uncontained engine event for both military and commercial aircraft. FAA Advisory Circular (AC) 20-128A, "Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure," provides additional guidance for completion of the numerical analysis although no specific methodology is identified [1].

Each aircraft manufacturer and engine company has its own methodology, and only recently has the U.S. military adopted a common tool, the Uncontained Engine Debris Damage Assessment Model (UEDDAM), for its methodology to consider uncontained events in a more realistic manner. UEDDAM can handle the analysis for the release of the primary rotordisk segment plus smaller engine debris fragments in directions out of the plane of rotation.

In the case of military use of commercial derivative aircraft, there are usually two separate safety assessments required. The original aircraft must be certified by the FAA and EASA for the first. Second, following the modifications for the military, the same aircraft must again be safety-certified by essentially the same rules.

A common methodology for analyzing the hazard from uncontained engine debris would benefit engine manufacturers, air framers, and customers with increased reliability and reduced costs. It would result in confidence that the results for all the different agencies are in agreement. Further, it would reduce efforts in the case of multiple assessments both in the civil cases of aircraft or engine repair and in the case of military modification to a commercial aircraft.

The debris from an uncontained engine event consists of high-energy penetrators that range in mass from tens of grams (a few ounces) to a high of 135 kg (300 lbs) and that should be viewed as aircraft combat survivability damage mechanisms because they can perforate, slice, sever, crush, or dislodge flight-critical components or other aircraft critical components. Their velocity when exiting the engine cowling can be up to 305 m/s (1,000 ft/s). Any assessment methodology must model the effects of all debris potentially penetrating into the aircraft, passing into and through structural components, and impacting aircraft flight-critical components.

Thus, these assessments must evaluate both effects of damaged flight-critical components on their aircraft system function and the cascading effects that multiply degraded systems have on overall aircraft flight capability. The larger, more massive, debris fragments can also create structural and decompression failures. Therefore, an analysis methodology would require both physical (e.g., finite element) and functional modeling of all the aircraft components within the zone of debris expansion from an engine.

In the case of the Qantas Airbus A380 incident, the uncontained engine debris cut electrical and hydraulic lines in the leading edge of the wing, causing the loss of multiple systems. Additionally, two fuel tanks were penetrated, causing significant fuel loss and creating a fire hazard. Although damage began with a single-engine event, the cascading damage effects quickly led to more than 50 automated system warnings to the crew regarding systems failures or impending failures. Civilian commercial aircraft are designed with redundancy for reliability and safety, such that if a single system fails, another system can provide the same or similar function. However, as Dr. Robert Ball described in his book *The Fundamentals of Aircraft Combat Survivability Analysis and Design,* redundancy without effective separation is only reliability and not survivability (avoiding or withstanding the damage effects of a damage mechanism) [2].

In the late 1990s, the FAA initiated an effort to develop an assessment methodology that would model of all the aircraft components within the zone of debris expansion from an engine. The Naval Air Warfare Center Weapons Division (NAWCWD) in China Lake, CA, was funded to develop a tool to assess the hazard from an uncontained engine debris event. This effort resulted in a computerized methodology for hazard assessment based on existing, well-established, and well understood tri-Service vulnerability assessment methodology. The UEDDAM code is based on two principal vulnerability assessment codes: FASTGEN and the Computation of Vulnerable Area Tool (COVART). Each of these codes has been used for more than 25 years for the assessment of damage effects on an aircraft from incident kinetic energy penetrating objects (i.e., missile fragments).

As shown in Figures 2 and 3, UEDDAM models both the physical and functional characteristics of all aircraft components within the debris zone, the functional relationships of all flight-critical components and systems, the penetration of the debris through the aircraft, and the damage characteristics of debris against component. Then it sums up the results into a probabilistic "hazard level" of an event as a function of aircraft flight phase.

UEDDAM requires an input of a three-dimensional (3D) geometric description of aircraft component positions within the aircraft and, thus, in relationship to each other. The description ("aircraft model") uses a specific input format, a format that can be processed by FASTGEN to develop debris travel vectors ("rays") through the aircraft and identify which components are intercepted by each ray and the geometry of this intersection. These debris rays are then used in COVART to assess the penetration depth the debris would be elected to achieve along each ray. COVART identifies which critical components are hit and gathers the probability of component damage of each component hit. Naturally, this subprocess also requires input data on damage characteristics associated with every possible critical component. COVART will also predict the effects on overall system function as a result of critical component damage; this prediction is accomplished by using an input file that defines component/system functional flow characteristics. UEDDAM then post-processes the output data from COVART, which uses FASTGEN rays to yield the hazard levels as a function of a particular debris event.

Adopting an assessment methodology such as UEDDAM results in a universal standard and uniformity of debris hazard evaluation across the involved agencies. Maintaining the 3D aircraft geometry model and its component/system functional flow data generated by aircraft manufacturers during their initial hazard assessment would simplify later debris hazard reassessments required by maintenance, repair, or military-modification to a commercial aircraft. And because UEDDAM already exists; many see this this tool as the low-cost solution to creating this assessment standard for both commercial and military. ASJ

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Mr. Christopher Adams is the Director of the Center for Survivability and Lethality at the Naval Postgraduate School in Monterey, CA, where he currently teaches combat survivability. He is also the former Associate Dean of the Graduate School of Engineering and Applied Sciences, and he has more than 20 years of operational flight experience in F-14s and EA-6Bs, serving multiple tours in Iraq and Afghanistan. Mr. Adams holds a B.S. in aerospace engineering from Boston University and an M.S. in aerospace engineering from the Naval Postgraduate School.

Mr. John Manion is currently the Survivability Assessment Branch Head for the Naval Air Warfare Center Weapons Division, in China Lake, CA. He has approximately 30 years of combined Government and industry experience in combat aircraft survivability research, design, testing, and analysis. Mr. Manion holds a B.S. in mechanical engineering from the University of Pittsburgh and an M.S. in systems engineering from the Naval Postgraduate School.

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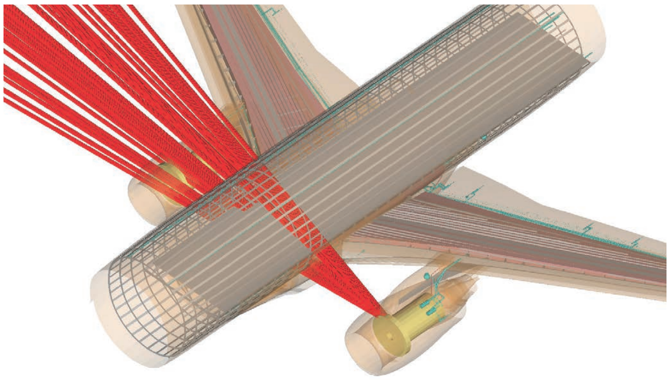

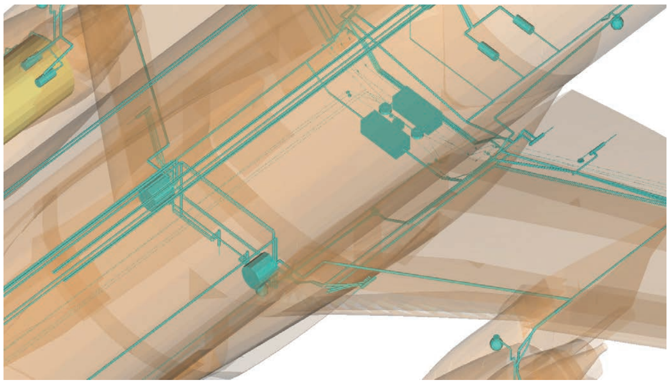

Figure 2 UEDDAM Simulated Engine Debris (left)
Figure 3 Hydraulic Pressure Line in a Generic Twin-Engine Aircraft (right)

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https://smdsymposium.org/

23rd Advanced Technology Electronic Defense Systems (ATEDS) Conference
29–30 August in San Diego, CA
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SEPTEMBER

MSIC SAM Symposium
12–14 September at Redstone Arsenal, AL

MSS Electro-Optical & Infrared Countermeasures
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https://www.sensiac.org/external/mss/meetings/list_meetings.jsf;jsessionid=3E4E3257728F06DA8D1DC303872F23AD

JAS FY17 Program Review
19–21 September at Nellis AFB, NV

OCTOBER

Rotorcraft Structures and Survivability Technical Meeting
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www.vtol.org/structure

Precision Strike Technology Symposium
24–27 October in Laurel, MD
http://www.precisionstrike.org/Events/8PST/8PST.html

NOVEMBER

NDIA Aircraft Survivability Symposium
7–9 November in Monterey, CA
www.ndia.org

5th Annual AOC International Symposium and Convention
28–30 November in Washington, DC

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