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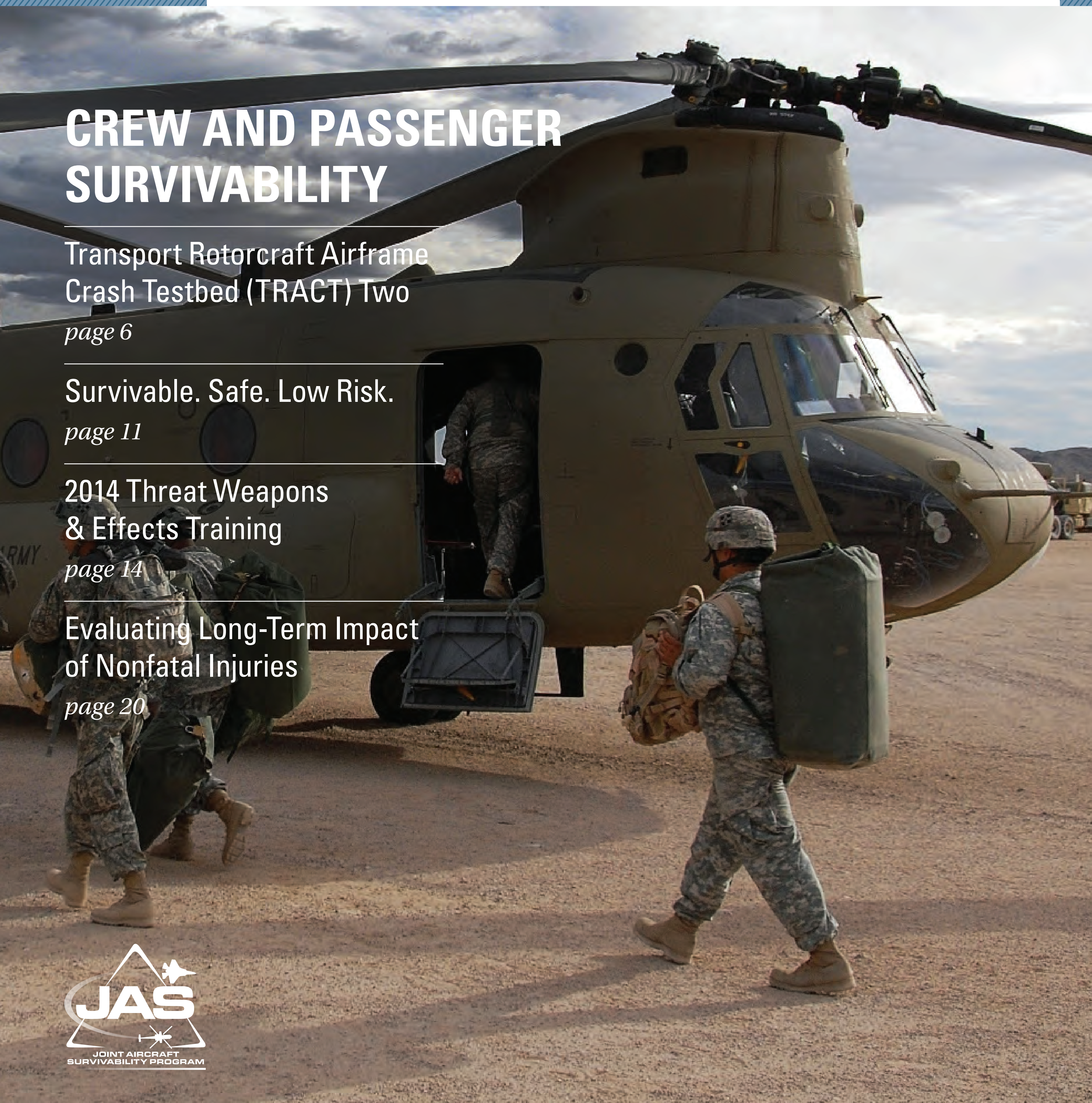

CREW AND PASSENGER SURVIVABILITY

JOINT AIRCRAFT SURVIVABILITY PROGRAM

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On the cover:
Soldiers prepare to board a CH-47F at the National Training Center, Fort Irwin, CA, in November 2007

TABLE OF CONTENTS

A follow-on helicopter drop test at the National Aeronautics and Aerospace Administration (NASA) Research Center in Langley, VA, will take another close look at cabin crash behaviors and crashworthiness innovations.

Survivable. Safe. Low risk. For anyone who has ridden in an airplane, a primary human consideration for being a passenger relates to any and each of those words. Every passenger expects the aircraft to be survivable, safe, and relatively risk free.

The 2014 Threat Weapon and Effects Training (TWET) took place on Hurlburt Field, Okaloosa County, FL, and at Eglin Air Force Base (AFB), Fort Walton Beach, FL, 22–24 April 2014. This annual training is presented by the Joint Combat Assessment Team (JCAT), sponsored by the Joint Aircraft Survivability Program Office.

To demonstrate an integrated platform solution that exemplifies both operational durability and total survivability without deleterious effect on mission performance, the US Army's Aviation Development Directorate–Aviation Applied Technology Directorate (ADD–AATD) and Sikorsky are executing the Combat Tempered Platform Demonstration (CTPD). CTPD integrates and demonstrates enhanced aircraft and crew/occupant protection, improved battlefield durability, and reduced threat vulnerability. The integrated approach to vulnerability reduction enables the survivability requirements for current and future aircraft to be realized more efficiently.

20 EVALUATING LONG-TERM IMPACT OF NONFATAL INJURIES

by Latrice Hall

Currently, personnel survivability studies primarily focus on the Soldier surviving injuries in combat and not necessarily on how nonfatal injuries affect the ability to perform everyday functions after treatment and recovery. Advancements in protective equipment and protection strategies, which are a result of these survivability studies, have greatly reduced the number of killed in action and have increased the number of wounded in action. Because of the increase in survivability, there is a need to characterize the effect of nonfatal injuries on long-term quality of life. A recently published metric called predicted Functional Capacity Index (pFCI) quantifies long-term functional limitations one year post injury.

23 EXPANDING AIRCRAFT COMBAT SURVIVABILITY TO INCLUDE FORCE PROTECTION

by Christopher Adams

The U.S. military Services design aircraft to operate in both normal and combat flight environments. The normal flight environment includes day-to-day operations conducting routine missions such as training and humanitarian assistance, with the usual takeoffs, transits, and landings. It also includes the natural hostile environment with its brownouts, severe turbulence, lightning strikes, bird strikes, midair collisions, and crashes. The combat (or man-made hostile) flight environment includes traditional combat with enemy forces using surface-to-air and air-to-air guns and missiles, as well as on-board terrorist threats, such as suicide bombers and bombs in suitcases.

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NEWS NOTES

By Dennis Lindell

RON KETCHAM RETIRES!

Figure 1 Scott O'Neil, SES, NAWCWD Executive Director (left), congratulates Ron on his Meritorious Civilian Service Award.

Ronald L. Ketcham, chairman of the Joint Aircraft Survivability Program (JASP) Survivability Assessment Subgroup, retired from civil service on 30 May 2014, after 30-plus years at China Lake. Ron began his career as a junior professional at the Naval Weapons Center in September 1982 working as an industrial engineer for system safety; after his JP tours he moved permanently to the Anti-Air Warfare Branch in the Weapons Planning Group (*aka* "Code 12") as an operations research analyst. While there, he worked on a number of projects, including: F-14 Tomcat Tactics, EA-6B EW Software Analysis, Sidewinder, RF Fire Control Fusion Algorithms, Joint Direct Attack Munition, and the Airborne High Energy Laser Weapon System. He also developed a model called SPADE (Simulated Point Area Defense Engagements) to study fleet defense effectiveness against cruise missiles. It was while working on SPADE that he began to interact off and on throughout his career at Code 12 with the Combat Survivability Division.

Around 1985 Ron decided he wanted to leave the desert and see the world, so he went to work for Lockheed skunkworks at the Burbank Airport; while at Lockheed he did modeling, simulation, and analysis for multiple platforms. But, apparently missing the wide-open spaces, he returned to China Lake after a couple of years to work in Code 12's Strike Warfare Branch. From the desert he soon was sent off to do two tours in Washington, DC: one to support the A-12 program (we won't blame you for that one, Ron), and the second at Space and Naval Warfare Systems Command to complete a tour requirement of the Senior Executive Management Development Program.

After being back at China Lake for a year Ron took over project management and development of the Analyst's Workbench, a tool for analyzing weapons systems in conceptual development; he was able to see it successfully applied to a Carrier Load-Out Study.

In 1997, Dave Hall called Ron and asked if he would work on a detail with the Survivability Division as a member of the Joint Accreditation Support Activity (JASA). He accepted and shortly became the accreditation lead for the Joint Strike Fighter (JSF) program. He also supported other accreditation projects, including the Coast Guard Deepwater program. And as a member of JASA, Ron chaired the second M&S Credibility Workshop in Reno, NV, in 2001.

Ron became the Branch Head of the Naval Air Warfare Center Weapons Division (NAWCWD) Survivability Assessment Branch in 2001, supporting a variety of Navy and Marine Corps aircraft and weapons programs including F/A-18, V-22, Tomahawk, and others. That same year Ron also took over as chair of the JASP Survivability Assessment subgroup and became a member of the executive board of the National Defense Industrial Association Combat Survivability Division (CSD). Ron chaired the 2011 CSD Aircraft Survivability Conference in Monterey, CA: thanks to Ron, this was the first year that the conference had a golf tournament, and Ron took up golf just so he could participate in the tournament! Since then he has become an avid golfer and plans to continue playing and improving his game in retirement.

In recent years, Ron has applied his modeling, simulation, and accreditation expertise to support the Joint Technical Coordinating Group for Munitions Effectiveness Endgame Manager tool, serving as chair of the Methodology Review committee. He recently served as product quality manager for the Joint Anti-Air Combat Effectiveness/Joint Anti-Air Model/Suite of Anti-Air Kill-Chain Models and Data program.

Upon his retirement, Ron was presented the Navy Meritorious Civilian Service Award by Scott O'Neil, the NAWCWD Executive Director and Director of Research and Engineering (Code 4.0); the award was signed by Rear Adm. Mike Moran, NAWCWD Commander. Ron's citation reads, in part,

"For significant technical and leadership achievements in the development and advancement of Modeling & Simulation capabilities for the evaluation of Mission Effectiveness and overall Combat Survivability assessments . . . Your

unequalled talents as a modeling and simulation expert, as well as your innate ability to formulate requirements for complex modeling systems, have been vital to the unparalleled success of the Survivability Assessment Branch. You are an unselfish and effective mentor, a visionary leader, and a highly valued member of the NAWCWD team. Your many noteworthy achievements and sustained superior performance are in keeping with the highest traditions of the Naval Service . . ."

Ron is retiring to Las Vegas and will be living on the 13th fairway of the Los Prados Golf Course. ASJ

JCAT CORNER

by Greg Fuchs

The Joint Combat Assessment Team (JCAT) has seen a busy year. This past spring saw another JCAT assessor training cycle complete, resulting in over 15 new assessors. The 2014 Threat Weapon and Effects Training (TWET) made a return after a year's absence, giving JCAT assessors the ability to interact with professionals from across the aircraft survivability industry. The future will be a challenge as the JCAT footprint changes over the next year.

JCAT's annual assessor training was completed in three phases: a week at Fort Rucker, AL, in February (phase I); a week at the Naval Air Warfare Center, China Lake, CA, in March (phase II); and TWET in April (phase III). In addition to the JCAT assessors, the Army hosted Aviation Mission Survivability Officers (AMSO, formally known as TACOPS officers) from Combat Aviation Brigades (CAB) across the Army during phase I. These warrant officers attend the entire week of phase I to prepare them to collect the raw data and begin the aircraft combat damage reporting (ACDR) process. As the frontline survivability representative for their units, JCAT does and will continue to work with these pilots to collect raw data to be used in JCAT combat damage assessments.

TWET made its return this year after it was canceled in 2013 because of the sequestration. This culminating event in the training of new JCAT assessors provides the new forensics officers critical insight into aircraft survivability by receiving classes and briefings from military and industry experts across many disciplines. Hosted by the Navy JCAT detachment and held at Hurlburt Field, Okaloosa County, FL, and at Eglin Air Force Base (AFB), Fort Walton Beach,FL, this year's theme focused on threats in Asia. Attendees were able to see the effects of a directional style warhead against one of DOD's rotary-wing aircraft after a warhead demonstration.

Next year's TWET will be held at Hurlburt Field and at Eglin AFB from 28–30 April 2015. The Army's Aviation Survivability Development and Tactics (ASDAT) Team will host this event, which will focus on threats to aircraft 2015–2020.

JCAT's footprint will return to a continental-US-only system as US involvement draws to a close in Afghanistan. This ends a continuous presence that began August 2004 and has been stalwartly supported by members of the Navy, Marine Corps, and Air Force aircraft survivability professionals. JCAT's forward deployed presence has provided commanders, and their flying Soldiers, valuable information regarding the threat faced by aircrews in Iraq and Afghanistan. With this forward-deployed presence coming to a close, JCAT elements must now posture to rapidly deploy assessors around the world as the ASDAT Team has done since 2003. This is only the beginning of the challenges JCAT will face as the military withdraws from Afghanistan and the entire military contracts.

As with any military organization, personnel changes have been a frequent occurrence. The ASDAT Team said goodbye to a long-time and valued member. Ms. Laurie Mitchell, the intelligence specialist for the team, has been accepted to a law school in Kentucky. The team bade her farewell in July; her knowledge, expertise, professionalism, and daily friendship will be missed.

Chief Warrant Officer 4 Robert Olson will be transferred to the Combat Aviation Brigade in the Republic of Korea. Finally, Chief Warrant Officer 4 Wayne Grimes has announced his retirement and will depart the team this winter for a spring retirement. ASJ

TRANSPORT ROTORCRAFT AIRFRAME CRASH TESTBED (TRACT) TWO

by Frank Colucci

A follow-on helicopter drop test at the National Aeronautics and Aerospace Administration (NASA) Research Center in Langley, VA, will take another close look at cabin crash behaviors and crashworthiness innovations.

A second drop test of the Transport Rotorcraft Airframe Crash Testbed (TRACT) is scheduled for this September in the Landing and Impact Research (LAND IR) facility at the NASA Research Center in Langley, VA. The first TRACT crash of an instrumented CH-46E helicopter full of anthropomorphic dummies last August gave NASA, Army, Navy, the Federal Aviation Administration (FAA), and industry researchers baseline data to correlate with photogrammetric tools. TRACT lead test engineer Martin Annett explains, "I would say the biggest thing we got out of it was the high-speed video and being able to fuse that video with the responses of the crash test dummies. We were able to coordinate when the peak loads occurred with the timing of that video." With the same tools, the next TRACT test will evaluate crushable floors, active seat restraints, and other crash-attenuating technologies. "Generally speaking, everybody who participated before will be participating again with their experiments."

TRACT experiments are not tied to any one rotorcraft design effort, but they may help designers of some joint-service Future Vertical Lift (FVL) helicopter or tilt rotor better protect aircrews and passengers. Unlike today's crashworthy helicopters optimized for vertical impact from a hover, FVL rotorcraft will need full-spectrum crashworthiness. Annett explained, "If you're going to design things like FVL concepts, how do you capture the aspects you want? . . . Impact velocity, terrain—all that will feed forward into how you design the airframe." TRACT data may shape future crashworthiness specifications like the MIL Standard 1290 first applied to the UH-60 Black Hawk in the 1970s. "I think

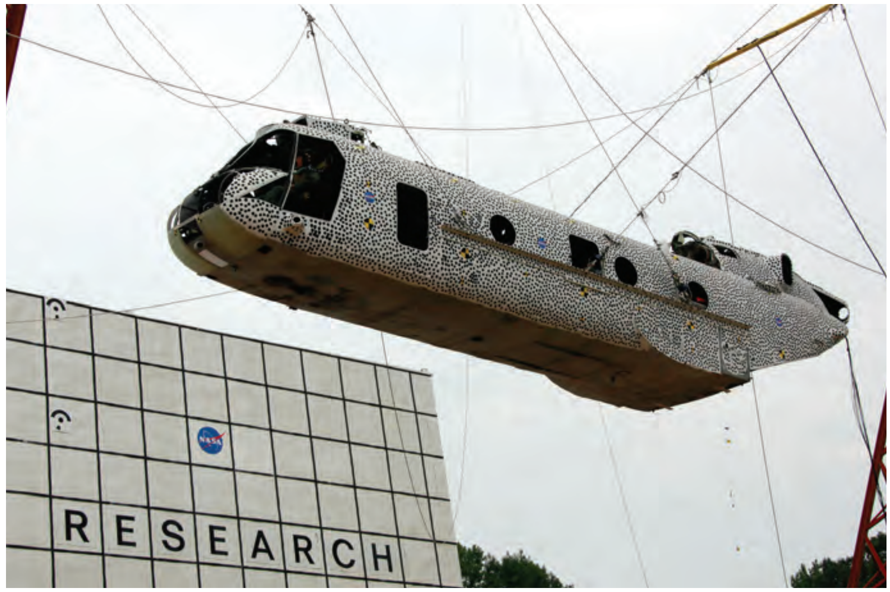

Figure 1. The NASA LAND IR facility dropped the first TRACT in August to collect baseline data for another crash in 2014. (NASA)

the airframes that came out of there are in very good shape—like the Apache and the '60," observed Annett. "We're not looking to redo requirements; we're looking more to understand the overall physics of what's happening inside."

Dynamic crash data may also help define active crew restraints and other safety systems inside the vehicle. Annett noted, "We have a velocity and attitude. What we don't always know is what will happen to the occupants." Sitting, standing, and litter-reclining "occupants" in the first TRACT crash included 13 instrumented crash test dummies and two uninstrumented mannequins. The LAND IR pendulum at Langley swung the retired Marine Phrog from 30 feet and severed suspension cables just before impact. The helicopter hulk hit the dirt track at 26 feet per second (fps) vertically and 35 fps horizontally—calculated survivable crash parameters. Annett observed, "People said it didn't look that bad on the outside; then you see what happened inside." Cameras, accelerometers, and a video game motion tracker all captured crash data still being analyzed for upcoming experiments.

The second TRACT airframe will, for example, replace aluminum shear-webs with energy-absorbing crushable composite floors. "The idea for that is we have some NASA concepts for shear webs in the subfloor," said Annett. "We would isolate out different frame sections. That allows us to put different concepts in different frames." NASA Langley technicians are fabricating several carbon-aramid floor structures. One has alternating inverted cones instead of sine-wave beams to begin the crush from either top or bottom. Another concept comes from the Deutsches Zentrum für Luft- und Raumfahrt, or DLR, the German space agency, working with manufacturers in Australia and New Zealand. "There's been some work going

Figure 2. The CH-46E was painted with a polka dot pattern for photogrammetry measurements of airframe deformation. (NASA)

on outside the US in composite crashworthiness," said Annett. "I proposed we put their design in under the floor."

CONTROLLED CRASHES

TRACT is part of the Fundamental Aeronautics Program Rotary Wing Project of the NASA Aeronautics Research Mission Directorate. Crash conditions inside the first CH-46 were also of interest to the US Army Aeromedical Research Laboratory (USAARL), the Naval Air Systems Command (NAVAIR) Crashworthy System Branch, the FAA Civil Aeromedical Institute (CAMI), and Cobham Life Support. The Naval Air Depot at Cherry Point, NC, gave NASA researchers the crash test article. "The '46 was available, and there was something in the size of the airframe," said Annett. The all-metal CH-46 nevertheless predated modern crashworthiness standards. "We're just interested in the overall system aspect . . . The ultimate objective was to understand what would happen if we switched something that was metallic to composite—would it be better? Would it be worse?"

Stripped of engines, transmissions, and rotors, the TRACT airframe was painted white with 8,000 black dots on one side to support full-field photogrammetry. LAND IR engineers now use the video measurement technology on all of their tests to capture uncorrupted data. Annett noted, "We have historically used strain gauges. They work relatively OK for metallic structures. It's not as well understood how you would bond to a composite structure."

Two Phantom calibrated cameras provided high-speed imagery processed by Aramis motion analysis software able to track individual dots and map structural deformation in six degrees of freedom. "We can identify hot spots on the airframe—stuff that's deforming out-of-plane or in-plane," explained Annett. "We can not only get individual time histories of those dots; we can plot the temporal response of the deflection."

Umbilical cables carried signals to and from the instrumented airframe prior to the drop, but pendulum pyrotechnics ruled out wireless telemetry and led engineers to record crash data on the aircraft. Ruggedized solid-state recorders from the Diversified Technical Systems, Inc. (DTS) and Kistler collected over 340 channels of data. Annett observed, "I think that was one of the bigger technical leaps—being able to instrument that much on-board and record at the time of impact."

The second TRACT test will use the same measurement technology with modifications. "We're going to add more cameras this time," said Annett. Langley technicians have also tested a polycarbonate floor in a cabin section from the first helicopter. "One of the things we will hopefully do is develop a floor that's transparent so we can shoot down into the subfloor."

INTERIOR INSTRUMENTATION

USAARL researchers at Fort Rucker, AL, continue to analyze data from the first TRACT crash and plan to participate in the second. The laboratory has ongoing efforts to improve medevac equipment in Army helicopters and used the first TRACT crash to collect baseline dynamic response data on existing patient litters—two from the Army and one from the Marine Corps—riding a three-tier Marine CH-46 litter support system. (Army CH-47 stanchions stack litters four high.) According to USAARL research mechanical engineer Joe McEntire, "This test was not intended to evaluate emerging or developmental hardware, but to increase understanding of existing litter equipment performance."

Structural standards for helicopter litter stanchions are old, and McEntire noted, "The standards have not been upgraded in terms of crashworthiness the way the seats have been." Existing UH-60/HH-60/CH-47 litter specifications are also based on static rather than dynamic loads. The first TRACT test put loaded litters in a dynamic crash environment. "Our objective is to develop recommendations for dynamic loading conditions and to conduct additional studies to assess other performance metrics and occupant injury risks."

USAARL filled the middle of the litter stack with a Hybrid III automotive crash test dummy instrumented with load cells at the head, neck, chest, spine, and pelvis. Two uninstrumented dummies above and below provided representative occupant masses to put realistic loads on the litter system. The support system was also instrumented with triaxial accelerometers on each of the four hooks carrying the middle litter.

Recorded imagery of the first crash was revealing. "If you look at the video, it appears to be pretty benign, but the internal video reveals it's pretty harsh for most occupants with things collapsing and components breaking," said McEntire. "Our intent is to use some of this data we've collected to better understand what loads are required on the litter system." He added, "That's a structural design component. The other half we'll be looking at is the forces and accelerations applied to the patient in the litter and looking at those to establish injury criteria to see if they're appropriate . . . Many criteria are set for automotive car crash testing in a forward impact." USAARL may use either modern HH-60M or developmental litter concepts in the second TRACT crash.

Figure 3. Instrumented crash test dummies provided insight into the TRACT crash behaviors, including the effects on litter patients and occupants of side-facing seats. (NASA)

While Army researchers focused on litters in a crash, the FAA CAMI in Oklahoma City, OK, was interested in side-facing cabin seats and occupants. FAA Mid-States Public Affairs Manager Lynn Lunsford reported that the crush characteristics of the first TRACT fuselage produced loads significantly different from the idealized loads used in laboratory tests to qualify crashworthy seats.

Common automotive crash test dummies have heads and necks tuned for front and rear impacts. European side-impact dummies (EuroSIDs) are tailored to the kinematics of side-facing loads. CAMI researchers put a hybrid dummy—a EuroSID head and neck on a Hybrid III torso—next to a regular Hybrid III dummy in side-by-side energy- absorbing seats. In the first TRACT crash, both side-facing seats stroked down and reduced lumbar spine loads as intended. All parameters measured by the FAA dummy were confirmed well below the injury limits.

For the next TRACT crash, the FAA experiment will remain unchanged so that the effect of the added energy absorption of composite fuselage structures can be compared to the baseline data. According to Lunsford, "Results from the test series will help us determine if revisions are necessary to current side-facing seat testing standards in order to ensure an equivalent level of safety when compared to fore- or aft-facing crashworthy seats."

Up in the cockpit, Cobham Life Support outfitted the left-seat copilot dummy with the pretensioning aircrew restraint system (PARS). This active restraint uses a pyrotechnic gas generator to tension the dummy's shoulder harness and tighten the harness inertia reel on impact. Cobham PARS engineer Tony Ollive explained, "By pretensioning, it keeps the occupant sitting in the seat more correctly than they would be without it and at the back of the seat. In that position, you can take full advantage of the protection the [stroking] seat provides."

Figure 4. The Cobham PARS installed on the copilot's seat alone gave researchers comparative data on crash movements with and without an active restraint system. (NASA *via* Cobham Life Support)

Cobham engineers had tried the active restraint on fixed seats, but the NASA event provided the first flight test. The right-seat dummy was strapped into a conventional MA-16 inertial reel. "We were doing a direct comparison between the left-hand side and right-hand side with the same seat, harness, and dummy with and without PARS." NAVAIR sponsored the original PARS Small Business Innovative Research and provided the stroking seats and dummies for the first TRACT crash.

The PARS in the first test was bolted to the back of the copilot seat and triggered by a contact switch when the helicopter hit the ground rather than by the intended G-sensor. "We were aiming for the simplest test we could do," notes Ollive. "We weren't particularly interested in testing the G-switch. We really wanted to test the pretensioner." He adds, "The system worked as it expected it to. There is evidence of reduced head, chest, and neck motion in the dummy . . . We did a very simple test—we tied a string around the dummy's neck."

The first TRACT crash gave Cobham engineers data regarding the forces and moments on the head, neck and chest of the dummies. High-speed video correlated that data with events in the cockpit. "The most enlightening aspect of TRACT 1 was the ability to watch the interaction of the whole system," said John Hintenach, key campaigns director at Cobham Mission Systems Division. "When we saw the numeric results coupled with the relationship between the restraints, the seat, and the equipment the crewmember was wearing, it was truly insightful," Hinternach added, "Most importantly, we received confirmation that the PARS system reduced the injury sustained by the crewmembers." TRACT 2 will test the integrated PARS subsystem, including crash-sensing electronics.

The LAND IR pendulum previously crashed the Bell YAH-63 Advanced Attack Helicopter, the Bell D292 and Sikorsky S-75 composite airframes, and a Boeing MD500 with external crash attenuator. Saved from planned demolition, the onetime lunar landing training facility has been reconditioned and modernized with a larger bridge to drop 32-ton loads and a basin for water impact testing. NASA Langley engineers have photogrammetry technology for crash tests on dirt or concrete, and Martin Annett said, "We're working on being able to look clearly underwater and do the same kind of tracking." ASJ

SURVIVABLE. SAFE. LOW RISK.

by Penny T. Willard and Richard A. Moyers

Survivable. Safe. Low risk. For anyone who has ridden in an airplane, a primary human consideration for being a passenger relates to any and each of those words. Every passenger expects the aircraft to be survivable, safe, and relatively risk free.

The challenge for military aircraft is that the operational environment the plane is being exposed to antagonizes and works against survivability. The plane is more prone to being engaged with small arms fire, high-explosive ordnance, and a broad range of threats in between. Yet a common and primary consideration still remains to make that aircraft survivable—a challenge that for the first time was explicitly a part of the key performance parameters (KPPs) in designing the Joint Cargo Aircraft (JCA) to meet wartime requirements.

In 2009–2010, the US Army Research Laboratory (ARL) collaborated with the US Aeronautical System Center Engineering Directorate, Combat Effectiveness and Vulnerability Branch (ASC/ENDA) to conduct a ballistic vulnerability analysis on the JCA. Two analyses were conducted to assess the crew vulnerability and system-level vulnerability, which was comprised of both the crew and troops flying as passengers.

In the initial stages of modeling, legacy methods were used that roughly approximated the contributions of the crew to the overall architecture of the plane. The ComputerMan/pilot survey (CMPS) technique uses the high-resolution ComputerMan limb-state-to-performance model combined with the pilot survey performance results to provide levels of dysfunction using the Sperazza-Kokanakis (SK) traditional functional states (*e.g.,* assault, defense, reserve, and supply). These models have since been replaced by the tri-service Operational Requirement-Based Casualty Assessment (ORCA) model.

MAIS	Injury Level	Type of Injury
1	Minor	Superficial
2	Moderate	Reversible injuries: medical attention required
3	Serious	Reversible injuries: hospitalization
4	Severe	Life threatening: not fully recoverable without care
5	Critical	Non-reversible injuries: not fully recoverable even with care
6	Maximal	Nearly unsurvivable

Figure 1: Maximum AIS (MAIS) Scoring

MUVES-S2 is a material-based vehicle vulnerability model that assesses threat shotlines through a vehicle to determine what components are damaged, given an insult, and to what degree. Several onboard "components"' are the crew and passengers, which requires the use of MUVES-S2 to determine what specific insults may interact with those Soldiers/Airmen; these would subsequently be assessed through ORCA. The insights provided by ARL's MUVES-S2 and ORCA models allowed high-resolution assessments of levels of injury and, through mapping residual capability to required functions, a level of incapacitation over several periods of post-wounding time.

ORCA incorporates previously and newly developed injury criteria, models, algorithms, and a widely used injury-severity scoring system—the Abbreviated Injury Scale (AIS)—to characterize the threat to life and an individual's response to trauma from various types of insults. Using ORCA's embedded database of job descriptions, this injury characterization allows the assessment of remaining human performance (*i.e.,* physical, cognitive, and sensory). MUVES-S2,while used in previous aircraft assessments, provided component-level shotline analysis of penetrating fragments into the airframe; the MUVES-ORCA combination allowed the answering of questions not previously asked in other aircraft programs.

	Pilot/Copilot	Loadmaster	"GIB"
Takeoff	Tasks to Control A/C, Task to Communicate with ATC, Navigation Tasks, and Emergency Tasks	Personnel/Cargo Accountability, Emergency Tasks	X
Cruise	Tasks to Control A/C, Task to Communicate with ATC, Navigation Tasks, and Emergency Tasks	Personnel/Cargo Accountability, Emergency Tasks	X
Landing	Tasks to Control A/C, Task to Communicate with ATC, Navigation Tasks, Personnel Accountability, ID/ Exit A/C, and Emergency Tasks	Personnel/Cargo Accountability, ID/Exit, Emergency Tasks	Identify/Exit, Personnel Accountability

Table 1: General Functions to Task Mapping, by Crew Position

Job	A *job* is defined as a list of an individual's tasks.
Task	A *task* is made of *task elements*. A *job* can have one or more tasks.
Task Element	A *task element* a single activity with specific parameters. An instance of a task element is defined in the terms of elemental capabilities.

Table 2: Job Decomposition

ORCA assesses the level of injury in AIS for each injurious shotline through an individual's body region. ARL determined that the maximum AIS (MAIS) threat to life and need for definitive medical care acceptable is a MAIS 3 (serious). Figure 1 illustrates the severity scale of MAIS injuries. Furthermore, when mapping those injuries to incapacitation, ORCA's Operational Casualty (OpCas) output answers the question: "Can the person still do X, Y, or Z tasks?"

For the JCA mission, the authors first had to decompose the flight profiles and crew contributions to the aircraft throughout those profiles into specific crew functions. This addressed what individual pilots did to maintain the aircraft in flight, the tasks that load masters performed, and—in the case of passengers—what was expected of them from takeoff through landing.

As illustrated in Table 1, those required functions allowed the authors to aggregate tasks into specific job descriptions that ORCA used to assess incapacitation. Table 2 describes the mapping process from task to job. These jobs are then linked to the specific component of the JCA target description (see Figure 2) such as a pilot/copilot, a loadmaster, or a "guy-in-back" (GIB).

With the assumption of redundancy, either pilot or copilot fulfilled the critical functions of maintaining flight while either of the load masters contributed to secondary functions of the aircraft cargo.

In traditional uses of ORCA, each crew member would be assigned a specific job. However, given the unique nature of pilot/copilot taskings and built-in redundancies, these jobs had to be built in a subtle but powerfully different manner. In Table 1, the mission that the aircraft was undergoing, coupled with the phase of flight (vignette) the aircraft was in along that mission, bound the pilot team to required functions. As an example, if the mission was to fly cargo a long distance, but the aircraft was already in flight when it was struck by anti-aircraft fragmentation, the pilot team would have to fulfill all of the tasks associated with the airborne-landing mission profile, regardless of which pilot executed each of those tasks. Failure of any of those tasks results in an incapacitation.

Figure 2. Aircraft Configuration: Crew

So the principal difference between the typical use of ORCA and those used in the JCA analysis is that in a traditional use, the job is mapped to the person. In the airborne jobs the person is mapped to the job performed. This allows the aircraft to continue so long as the pilot or copilot is able to perform the function of the aircraft. That is, in order for the task to be failed, both the pilot and copilot had to be incapable of performing it.

The two vulnerability analyses (system level and crew vulnerability) then, answered two different question sets. In the system level analysis, three types of system-kill levels were assessed:

- Attrition: the incapacitation of both pilot and copilot in fewer than 30 seconds, which used the Operational Casualty (OpCas) metric from ORCA. OpCas is a binary assignment of one (can perform the job) or zero (cannot), so that failure of both pilot and copilot means a loss of the aircraft.
- Fly and land: the inability to perform all of the tasks at a certain time (*e.g.,* five, 15, or 30 minutes post injury) drives the analysis to determine how much longer the aircraft can stay in flight before it must have landed safely. Time beyond that window may result in attrition.

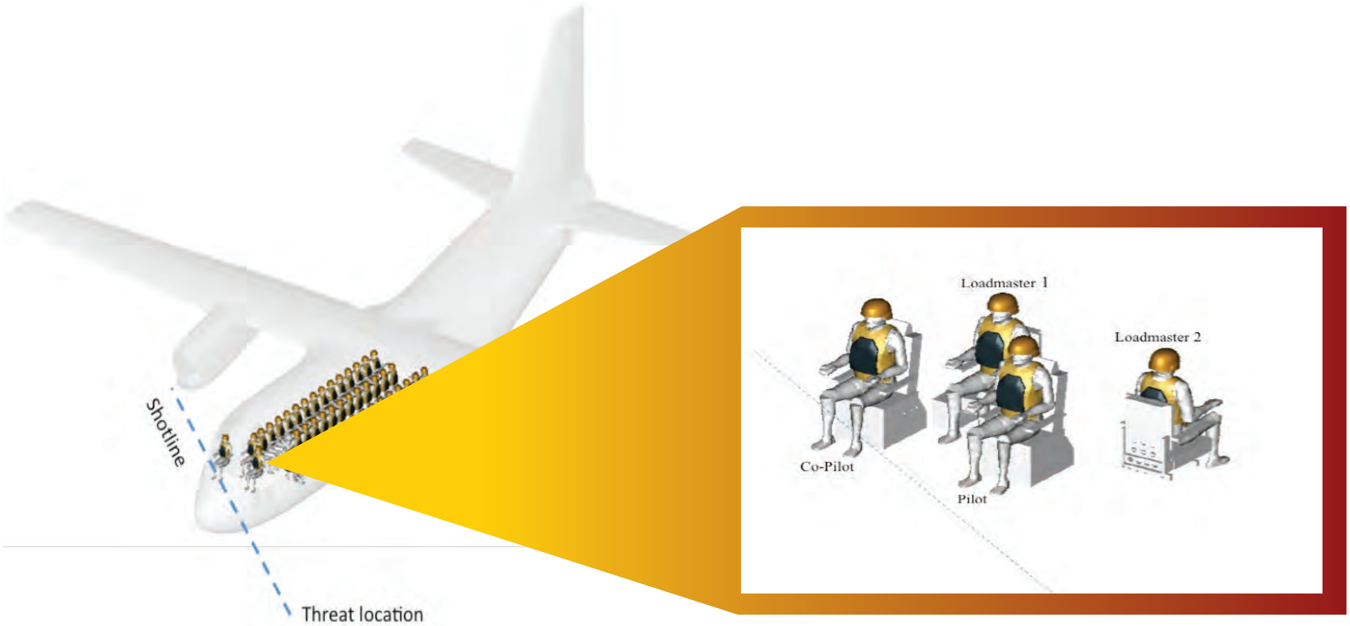

Figure 3. Example of Combined Threat-Target Shotline Analysis (Notional)

- Mission abort: if any troop member or crew sustained a MAIS 3 or greater, the aircraft would simply return to station short of its designated mission. Of course, loss of both the pilot and copilot leading to attrition supersedes a mission abort.

The results of each threat-target combination allowed the analysts to determine a probabilistic outcome of how well the aircraft performed against the threat (see Figure 3). Furthermore, it allowed the developers to identify specific vulnerable locations. They could then add armor to those locations without up-armoring the entire aircraft and weighing it down, even if a complete through-and-through perforation hits nothing critical to the mission. This analysis directly supported the JCA's full-rate production milestone decision.

While survivability has always been a concern for our systems, the JCA analysis provided the opportunity to address human survivability in an airplane. Adding this KPP to the requirement allowed the partnership to specifically address human vulnerabilities in a high-resolution and meaningful manner not until recently touched. ASJ

2014 THREAT WEAPON AND EFFECTS TRAINING

by Scott Quackenbush, LCDR

The 2014 Threat Weapon and Effects Training (TWET) took place on Hurlburt Field, Okaloosa County, FL, and at Eglin Air Force Base (AFB), FL, 22–24 April 2014. This annual training is presented by the Joint Combat Assessment Team (JCAT), sponsored by the Joint Aircraft Survivability Program Office.

TWET is an excellent venue for representatives from Department of Defense (DoD) organizations, industry partners, and other government agencies to meet and network with other people who are interested in or work in the aircraft survivability field.

JCAT, as its name implies, is a joint organization, comprised of Army JCAT, staffed by members of the Aircraft Shoot Down and Assessment Team, Air Force JCAT, and Navy JCAT, made up of Navy reservists from the In-Service Engineering & Logistics (ISEL) unit.

Each year, the three services share responsibility for conducting TWET. This year the training was led by Navy ISEL and organized by LCDR Scott Quackenbush, with a focus on the likely source and capabilities of future threats.

JCAT's mission is to perform hands-on forensic assessments on combat damaged aircraft. JCAT assessments are used to provide the forward-deployed operational commander with a near–real time fact-based explanation of what happened to the aircraft, as well as provide the aircraft survivability community with a detailed, pervasive record of damage sustained by the airframe.

Figure 1. The 2014 Threat Weapon and Effects Training was another great success.

JCAT combat assessors have evolved into highly trained combat battle-damage and threat weapon analysts. Their training blends a highly technical and analytical capability with an in-depth knowledge of aircraft capabilities, friendly and enemy tactics, and enemy threat weapons capabilities and their effects. It includes continuous learning with threat weapons effects and munitions experts from the DoD (*i.e.,* Missiles and Space Intelligence Center, National Ground Intelligence Center, Naval Air Warfare Center Weapons Division Weapons Survivability Laboratory, as well as explosive experts from the Federal Bureau of Investigation and the Bureau of Alcohol, Tobacco, and Firearms). The proficiency of a JCAT combat assessor is continuously evaluated and refined through collaboration with other service components, intelligence updates, and the training curriculum.

TWET serves as continuing education for JCAT assessors, providing education and training in threat systems, combat-damage assessment, and engineering analysis of data gathered. JCAT has had team members overseas supporting Operation IRAQI FREEDOM (OIF)since 2003, Operation ENDURING FREEDOM (OEF) since 2008, and currently supports forward detachments in Afghanistan at Camp Leatherneck, Bagram, and Kandahar. JCAT damage assessment reports are widely disseminated in near real time to coalition soldiers, affected platform program offices, and the

Figure 2. An Army JCAT assessor instructs a TWET attendee during the field portion of the training.

Figure 3. The Coveted 2014 TWET Challenge Coin.

broader scientific/survivability communities. To date, over 1,300 JCAT assessments documenting combat damage on aircraft have been completed for use by intelligence as well as future survivability engineering analysis.

In total, 188 attendees participated in the 2014 TWET. The schedule of events included briefs, which took place at the Hurlburt Field theater, as well as field training, which utilized Eglin AFB test ranges. Transportation to and from the range was provided for all participants, and typically took up one afternoon of the three-and-a-half-day schedule. This year's presentations, made at the classified level, covered an analysis of combat damage from all of OEF and OIF, current and future threat systems, and survivability advances. Field activity included hands-on training with a Stinger trainer, observation and assessment of live fire assets, and close observation of target damage from a "just occurred" live fire. ASJ

AIRCRAFT SURVIVABILITY RATING

by Jordan Kaye, Mark E. Robeson, and Nathaniel Bordick

To demonstrate an integrated platform solution that exemplifies both operational durability and total survivability without deleterious effect on mission performance, the US Army's Aviation Development Directorate–Aviation Applied Technology Directorate (ADD–AATD) and Sikorsky are executing the Combat Tempered Platform Demonstration (CTPD). CTPD integrates and demonstrates enhanced aircraft and crew/occupant protection, improved battlefield durability, and reduced threat vulnerability. The integrated approach to vulnerability reduction enables the survivability requirements for current and future aircraft to be realized more efficiently.

Vulnerability assessments are an important part of meeting the survivability requirements for many aircraft. Traditionally, these assessments consider the aircraft both at a system and subsystem level to determine how survivable the aircraft will be against certain threats. Typical assessments consider how likely a component is to fail after ballistic impact, based on a damage modes and effects analysis (DMEA), and then track the failure through a failure analysis logic tree (FALT) to predict an end effect on the aircraft.

End effects are considered the mission outcomes. Typically there are three outcomes analyzed: mission abort (MA), forced landing (FL), and attrition (At). Each outcome is assigned a probability of kill given hit ($P_{K/H}$) and a vulnerable area (Av). The $P_{K/H}$ and Av are often used for the validation of aircraft vulnerability requirements, armor trade studies, and protection optimization. In addition, assessments typically consider different mission points, such as high/fast and low/slow. The output of these assessments consists of one $P_{K/H}$ per mission point per mission outcome per threat. For example, for an assessment consisting of two threats, three mission outcomes, and two mission points, there will be 12 separate $P_{K/H}$ values as output.

Turning these multiple output values into one usable number to rate the vulnerability of the aircraft or assess the impact of a single technology has proven to be a challenge. In addition, while these assessments account for component and system-level ballistic testing of the aircraft, they do not account for any aircraft reaction in the combat environment. To assess the vulnerability of an aircraft more accurately, combat data can be used to add an additional layer of statistical reasoning to refine the vulnerability assessment and reduce the multiple outputs of an assessment to a single number. The additional statistical layer and reduction to a single number enable an easier interpretation of the vulnerability of current or future aircraft and provide a means to further assess how various survivability features can improve the overall survivability of the aircraft.

Required data

When evaluating the survivability of a current or developmental aircraft—that is, determining its survivability rating—a key consideration is how to combine vulnerability assessment output with data from combat reports. For the present paper, it is assumed that a traditional vulnerability assessment is being performed; the assumptions made in that portion of the assessment will not be considered herein. Combat data will not always fall exactly into categories of threat, mission outcome, or mission profile in the way that a vulnerability assessment does.

Threat

Typically, an aircraft requirement will determine what threats are included in a vulnerability assessment. In combat there are often identified threats with many variations, unidentified threats, and multiple threats used simultaneously. Therefore it is important that more generic threat groups, such as small arms or heavy machine guns, are used for combat data instead of a specific threat. It should be determined in the beginning of the assessment what category certain threats will fall into, and also how to divide and account for attacks using multiple threat categories.

Mission Outcome

As mentioned previously, vulnerability assessments typically consider three mission outcomes: MA, FL, and At. Combat data supports a fourth category representing no effect on the mission: not applicable (N/A). An N/A outcome represents when the pilot of the aircraft is either unaware of the damage or knows of the damage but continues the mission to completion. This category helps to account for pilot decisions in the mission, which are not considered in typical vulnerability assessments. Using this data more accurately predicts the real number of times that a more severe mission outcome occurs.

Mission Profile

While mission profile does not need to be accounted for in combat data, it is an integral part of the vulnerability assessment. In determining a survivability rating, mission profiles are used to create a weighted average value for the aircraft. This is based on mission profiles typically developed in aircraft design. The mission profiles can be analyzed to see how long the aircraft is in each mission condition assessed (for instance high/fast or low/slow). This length of time can then be used to determine the percentage of time the aircraft will be in the state of vulnerability associated with a given mission profile. This approach allows multiple $P_{K/H}$ values to be collapsed into one weighted value, a key attribute of the present survivability rating methodology.

COMBAT DATA

Collection

Combat reports must include, at a minimum, the type of aircraft, the assessed threats (including number of impacts), and enough information to determine the mission outcome. Reports should also be applicable to the aircraft being analyzed. Mission outcome is often left to the discretion of the analyst, as there may be some reports that do not directly state if the aircraft finished the mission or aborted. (This illustrates the importance of detail in the combat reports.) When analyzing the combat reports, the analyst must carefully track and document relevant data from each report to fully substantiate any conclusions. When collecting relevant data from combat reports, the number of impacts on the aircraft (separated by threat) and the mission outcome are essential for determining the survivability rating. The statistical methods described in detail later are based on this aircraft impact data.

Analyzing

Analyzing the relevant combat data requires that it be reduced to percentages so that it can be applied in statistical methods discussed later. The data must be sorted for the following values:

- Total number of aircraft impacts, broken down by threat group and mission outcome
- Percentage chance of mission outcome, based on all threats
- Percentage chance of encountering an individual threat group, inclusive of all outcomes

As mentioned previously, when reviewing combat data there may be cases in which a threat impacts an aircraft, but the aircraft continues the mission to completion, resulting in a mission outcome category of N/A. It is suggested that these data points still be used when calculating the outcome probability discussed in the next section. The N/A outcome allows for the resulting survivability rating to better represent what happens in combat, as opposed to what is predicted to happen in the vulnerability assessment.

CALCULATING SURVIVABILITY RATING

Reducing Mission Points

In the present methodology, the first step in calculating the survivability rating is to reduce the data in the vulnerability assessment. This involves using a predetermined mission profile, and determining how long the aircraft will be in each of the mission points during that flight profile. For example, if there are four mission points analyzed in the vulnerability assessment, the time in each point must be determined, and from this, the percentage of time in each point must be determined. Using these percentages, the weighted average $P_{K/H}$ for each mission outcome and threat can be determined, as shown in Equation 1.

$$P_{\left(\frac{K}{H}\right)(Outcome,Threat)} = \sum P_{\left(\frac{K}{H}\right)Outcome_{Mission\ Point}} * \%Time_{Mission\ Point}$$

Equation 1 Calculating Average PK/H for Each Outcome and Threat

Equation 1 should be applied for all mission outcomes, such that if three mission outcomes were analyzed, the result would be only one value for $P_{K/H}$ per outcome for each threat analyzed in the vulnerability analysis. If flight profiles are not available, using an equal weighting for all mission points would be acceptable.

Combining Threat Data

As previously described, relevant combat data should be sorted into the number of impacts on the aircraft per threat group per mission outcome. An example of this approach to sorting data, highlighting the outcome probability, is shown in Table 1. Note that all values used in Table 1 are notional, and therefore do not represent any actual data.

Threat Group	N/A	Mission Outcome		At	Threat Probability
		MA	FL		
A	20	10	3	0	51.5%
B	5	7	4	1	26.6%
C	3	5	2	4	21.9%
Outcome Probability	43.8%	34.4%	14.0%	7.8%	

Table 1: Example Threat Data

The other key type of data needed is the percentage of time that the aircraft encountered each threat group. This threat probability is represented as the total number of impacts from the threat group divided by the total number of impacts from all threats present in the data set.

Calculating Survivability Rating

With the three key pieces of data (weight averaged $P_{K/H}$, outcome probability, and threat probability) now determined, the survivability rating can be calculated. The first step is to calculate the expected value of $P_{K/H}$ for all threats combined. This is done using Equation 2:

$$E\left(P_{\left(\frac{K}{H}\right)(Outcome)}\right) = \sum P_{\left(\frac{K}{H}\right)(Outcome,Threat)} * Threat\ Probability$$

Equation 2 Calculating Expectxed PK/H for All Threats Combined

This expected value of $P_{K/H}$ should be calculated separately for each mission outcome. Note that this equation only combines the $P_{K/H}$ for threats. Next, the solutions from Equation 2 are used to combine all of the mission outcomes into one survivability rating. This survivability rating is given by Equation 3.

$$Survivability\ Rating = \sum E\left(P_{\left(\frac{K}{H}\right)(Outcome)}\right) * Outcome\ Probability$$

Equation 3 Calculating Survivability Rating

This survivability rating equation creates a weighted average of all outcomes and all threats to determine a single value to evaluate the chance of survival for the aircraft in combat.

LIMITATIONS AND USES

The greatest factor limiting the substantiation of the survivability rating is the combat database used. Since the survivability rating is dependent on data from combat, a limited data set will result in a less robust result. In addition, a survivability rating developed using combat data from a particular combat theater is applicable only to that theater. If the combat theater changes, the data points will no longer be as valid, since different threats may be encountered. By grouping the threats in larger, more general categories, the effect on the survivability rating caused by varied combat theaters can be reduced. Additionally, the data used to calculate survivability rating can be supplemented with predicted operational uses and encountered threats.

Interpretation

The survivability rating produces a single value, which represents the chance that hostile fire will affect an aircraft's mission. Since the rating takes into account different threats, different mission outcomes, and the mission profile, it can be interpreted as the percent chance that hostile fire will lead to a negative outcome during a given mission. Unlike the output of a traditional vulnerability assessment, the survivability rating quantifies not only the chance of a hostile attack in a given combat theater, but also the chance of actually being hit to the detriment of the mission.

Current Uses

Being able to statistically reduce a vulnerability assessment to a single survivability rating value can be helpful in the aircraft design process in that it simplifies the amount of relevant data needed. In addition, by considering what threats are the most likely to hit the aircraft based on data or predictions, aircraft system–level protection can be better optimized to be either more or less robust, depending on the survivability rating and relevant requirements. This capability can lead to the aircraft meeting survivability requirements while having the potential to reduce weight by optimizing protection.

Areas for Improvement

The survivability rating and methodology to generate it can be improved in a few ways. The primary area for improvement is better combat data. The larger and more detailed the database, the better and more accurate the survivability rating will be. Limitations in the combat data or in its analysis can lead to false conclusions being drawn from the rating.

Another way to improve the methodology is to determine how to change the incorporation of the combat data from something done after the vulnerability assessment into being part of the vulnerability assessment itself. If the assumptions made during the vulnerability assessment could more accurately reflect what the outcome of the ballistic damage will be, the parts of the survivability rating can be incorporated into the assessment. This would allow the current methods of using ballistic test data to define system reaction to be further expanded to begin to include pilot judgment and aircraft level reactions. Using statistical methods to collapse the multiple PK/H values would still enable simplified results.

Future Uses

The survivability rating could also be used to assess a future aircraft, if the predicted combat theater is known. Predictions can be made about the threat usage in that combat theater. This can allow for the expected value of $P_{K/H}$ (see Equation 2) to be calculated using predicted values. Calculating the survivability rating (see Equation 3) will be slightly more difficult because there will not be data for the outcome probability. However, data from similar aircraft can be applied, as long as it is applicable for threats and similar design, to make a prediction of how the aircraft will react to the threats.

Moving forward, Sikorsky and ADD–AATD will continue to apply the new aircraft survivability rating methodology during execution of CTPD. Furthermore, ADD–AATD will seek opportunities for broader application of the aircraft survivability rating to benefit the current Department of Defense (DoD) aircraft fleet, with a particular focus on rotorcraft. In coming years, the aircraft survivability rating methodology will provide an additional tool for enhancing the survivability of the evolving DoD fleet, including that being shaped by the Army's future vertical lift initiative.

CONCLUSIONS

A new methodology to rate aircraft survivability has been developed, making use of traditional vulnerability assessments for aircraft while adding in combat data to align the results more accurately with what is encountered in actual usage. The rating can be applied to current aircraft to help create a baseline value against which survivability and vulnerability improvements can be compared. The rating can also be applied to future aircraft to optimize survivability features. By taking multiple $P_{K/H}$ values from the vulnerability assessments and reducing them down to a single number, the relevant data becomes more manageable and allows for an easier comparison of results. This new methodology is not only applicable to fielded aircraft, but can also be applied to future aircraft and the development of requirements for more survivable aircraft fleet.

ASJ

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EVALUATING LONG-TERM IMPACT OF NONFATAL INJURIES

by Latrice Hall

Currently, personnel survivability studies primarily focus on the Soldier surviving injuries in combat and not necessarily on how nonfatal injuries affect the ability to perform everyday functions after treatment and recovery. Advancements in protective equipment and protection strategies, which are a result of these survivability studies, have greatly reduced the number of killed in action and have increased the number of wounded in action. Because of the increase in survivability, there is a need to characterize the effect of nonfatal injuries on long-term quality of life. A recently published metric called predicted Functional Capacity Index (pFCI) quantifies long-term functional limitations one year post injury.

The pFCI is an application of Functional Capacity Index (FCI) provided in the *AIS 2005—Update 2008 dictionary* [1]. The Abbreviated Injury Scale (AIS) is a global scoring system that classifies injuries based on type, location, and severity. The values for pFCI range from 5 to 1, where 5 is no functional limitation on daily life and 1 is maximum functional limitation. Therefore, to understand what the pFCI values mean, one must understand FCI.

FCI is a 10-dimensional index that characterizes long-term functional limitation on daily life one year after injury. The 10 dimensions characterized are eating, excretory, sexual, ambulation, hand/arm movements, bending/lifting, visual, auditory, speech, and cognitive function. Within each dimension there are three to six levels (A–F) that describe the level of functional limitation for that dimension. The index is written as letters, where each letter corresponds to the level of functional limitation for each dimension and an overall score. [2,3]

FCI was created by Dr. Ellen McKenzie, along with her colleagues at the Johns Hopkins Bloomberg School of Public Health and in partnership with the Association for the Advancement of Automotive Medicine and the AIS scaling committee. It was created as a companion to AIS, which is primarily a threat-to-life metric that does not sufficiently characterize long-term functional limitation. pFCI was created by lumping the overall score from the FCI into the five levels and assigning a score to each injury defined in the AIS dictionary. [2]

Because the data that serves as the basis for pFCI is based on civilian data, it was very important to perform analyses to determine if the metric is useful for military applications, as well as to determine if it provides additional information for survivability studies. The goal for this metric is not to replace currently used survivability metrics, but to be used in conjunction with existing metrics to understand the influence of survivable injuries on quality of life. With this in mind, several analyses were conducted to demonstrate the usefulness of this metric.

To determine if pFCI provides additional information that can be used to supplement survivability studies, the distribution of AIS severities versus the distribution of pFCI was investigated to understand how significant injuries are distributed across the body regions. Within the evaluation community for survivability studies pertaining to the US Soldier, significant injuries are defined as injuries coded AIS level 3 (serious) or greater. In terms of pFCI, all injuries that have an effect of long-term functional impairment were classified as serious injuries for the analyses discussed in this paper.

After reviewing the distribution of injuries, it was noted that the head and spine were the two body regions that sustained the most AIS serious or greater

MAIS	Injury Level	Head Injury Example
1	Minor	Minor laceration of scalp
2	Moderate	Major laceration of scalp, blood loss < 20%
3	Serious	Fracture of skull, penetration < 2 cm
4	Severe	Depressed skull fracture, penetration > 2cm
5	Critical	Depressed skull fracture, laceration of spinal artery
6	Maximal	Massive brain stem crush

Table 1: MAIS Legend with Examples

mpFCI	Injury Level	Head Injury Example
5	None	Penetrating injury to skull; superficial
4	Minor	Vestibulocochlear nerve laceration (cranial nerve)
3	Moderate	Large contusion of cerebellum
2	Severe	Penetrating injury to skull; major
1	Maximal	Massive brain stem crush

Table 2: mpFCI Legend with Examples

Figure 1: MAIS and mpFCI for 4 Grain Steel Fragment at 600 m/s

Figure 2: MAIS and mpFCI for 100 Grain Fragment at 900 m/s

injuries. The two body regions with the most AIS injuries that have a long-term effect on daily life were the head and lower extremities. The difference between these distributions shows that some AIS moderate and minor injuries, which are not considered significant injuries in terms of threat to life, could have a long-term effect on daily life. Also, the distributions show that injuries that are considered significant in terms of AIS severity may not affect functional limitations.

The pFCI scores were implemented in a personnel vulnerability model to demonstrate its usefulness for military applications. This personnel vulnerability model used by the U.S. tri-service vulnerability community is called the Operational Requirement-Based Casualty Assessment (ORCA) model. ORCA evaluates the effect of various battlefield insults such as blast overpressure, penetration, and acceleration on personnel targets to predict injuries and functional impairment [4]. The injuries that ORCA predicts are coded using the *AIS 2005 — Update 2008* dictionary, therefore, the implementation of pFCI was fairly straightforward. In terms of severity scales, both AIS severity and pFCI assume that the person received only one injury.

Since a single insult on a personnel target could produce multiple injuries, summary metrics are used to characterize overall severity for an individual. The summary metrics used are Maximum Abbreviated Injury Scale (MAIS) for evaluating threat to life and minimum predicted Functional Capacity Index (mpFCI) for evaluating quality of life. MAIS classifies injury severity on the basis of the injury with the greatest AIS severity value. mpFCI classifies functional limitation on the basis of the injury with the greatest effect on long-term functional limitation. The range of values and meaning for both metrics are located in Table 1 and Table 2.

A survivability analysis using penetrating threats was performed to further understand the benefit of using both metrics. Two different threats were analyzed to demonstrate the differences between MAIS and mpFCI. This analysis was performed to visualize how the vulnerable area changes as the threat changes, as well as where the two can differ for specific shot lines to the body. Figure 1 shows an example of a 4 grain steel fragment traveling 600 meters per second (m/s) against a represented personnel anatomy. A uniform distribution of shot lines to the body was modeled to sample all impact locations to the front of the body. The colors for each sample point represent the MAIS or mpFCI for all injuries along the shot line.

In Figure 1, injuries in the lower arms do not receive a MAIS value greater than 2, which means those injuries are classified as moderate or minor. For mpFCI, some injuries in the arms received an mpFCI value that were less than 5, which classified them as significant injuries relative to quality of life. This example shows that some minor and moderate injuries could be counted in assessing survivability, since they could cause long-term effects.

The second threat velocity combination was of a 100 grain steel fragment traveling at 900 m/s against a representative personnel target. The results in Figure 2 show there were several shot lines that produced significant injuries in terms of both MAIS and mpFCI. There were very few shot lines that had significant injuries in terms of MAIS that were not significant in terms of mpFCI; however those shot lines do exist. This demonstrative analysis shows that the agreement between the two metrics increases as the size of the threat increases, as expected, because of the significant levels of trauma.

pFCI allows analysts to characterize another aspect of survivability. Survivability does not only deal with being able to survive an injury, it also deals with the ability to recover from that injury. The AIS severity score, which characterizes an injury's threat to life, mainly addresses the ability to survive an injury. Using AIS and pFCI in conjunction allows analysts to not only predict threat to life, but also quality of life and functional limitations for a given injury. The results of the analyses show that minor and moderate injuries in terms of threat to life can significantly decrease long-term quality-of-life. Work is ongoing to continue to improve FCI to better model all types of civilian and military trauma. ASJ

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EXPANDING AIRCRAFT COMBAT SURVIVABILITY TO INCLUDE FORCE PROTECTION

by Christopher Adams

The U.S. military Services design aircraft to operate in both normal and combat flight environments. The normal flight environment includes day-to-day operations conducting routine missions such as training and humanitarian assistance, with the usual takeoffs, transits, and landings. It also includes the natural hostile environment with its brownouts, severe turbulence, lightning strikes, bird strikes, midair collisions, and crashes. The combat (or man-made hostile) flight environment includes traditional combat with enemy forces using surface-to-air and air-to-air guns and missiles, as well as on-board terrorist threats, such as suicide bombers and bombs in suitcases. [1]

Aircraft can be damaged, lost, or killed, and aircraft occupants injured or killed as they fly in both normal and combat flight environments. Three disciplines, or communities, share responsibility for preventing damage or loss of aircraft and protecting occupants from injury and death. System safety (SS) involves the application of engineering and management principles to identify hazards and then to eliminate the hazards or reduce the associated risks when the hazards cannot be eliminated. The expanded aircraft combat survivability (ACS) involves application of design principles to increase the capability of an aircraft and its occupants to avoid or withstand damage from a man-made hostile environment (*i.e.,* combat). Human systems integration (HSI) is a recently developed discipline that has a goal of optimizing total system performance and total ownership costs while ensuring that the system is designed, operated, and maintained to effectively provide the user with the ability to complete his or her mission. The HSI discipline will be described in an upcoming issue.

Although there are some similarities between these three disciplines, when it comes to system design techniques and protecting occupants, each has unique responsibilities to ensure users can effectively and safely operate their aircraft to accomplish their assigned missions. To identify the appropriate discipline responsible for preventing or mitigating each particular damage event, the flight environment in which the event occurs, the cause of the event, and the outcome of the event must be considered.

For example, consider event number one, consisting of an aircraft on a training mission (the aircraft is operating in the normal flight environment). The engine throws a fan blade, which results in an engine fire and the eventual loss of the aircraft and the death of all of the occupants in a crash. The event is caused by the hazard associated with the thrown fan blade, and the outcome of the event is a loss of the aircraft and death of all of the occupants in a crash. Because the event occurs in the normal flight environment and is the result of a mechanical failure, the event falls within the purview of the SS discipline.

Consider a very similar event, number two, in which the aircraft is on the same mission that the aircraft in event number one was training for, but this mission is in a combat zone. The cause of the event is a fan blade failure leading to a crash and the subsequent death of the occupants. This event was the purview of SS in the normal environment. Does the fact that the aircraft is flying in a combat zone in this event change anything?

Consider another event, number three, consisting of an attack aircraft with a single pilot on a close-air support mission in a combat zone (the aircraft is operating in the combat flight environment) that is attacked and killed by the launch, impact, and detonation of an infrared surface-to-air missile (IR SAM). The aircraft kill is due to the impact of a threat weapon, and in this example the pilot safely ejects. Because this event occurs within a combat environment and the aircraft kill is due to the IR SAM (a threat weapon), the event falls within the purview of the ACS discipline.

In a fourth event, a helicopter carrying troops is flying low to avoid detection in a combat zone (the combat environment), an example of threat avoidance. While flying at a low altitude, the helicopter collides with several electrical power lines and crashes. The aircraft kill and the occupant casualties are due to the collision with the power lines and subsequent crash, not to the damage mechanisms of an enemy weapon. The incident is due in large part, however, to the very existence of the threat (or air defense) environment. The helicopter is flying in a combat zone, but it is not shot down by a threat weapon; rather it crashed as it was attempting to avoid a weapon engagement. Which discipline has the responsibility to prevent or mitigate this event and to protect the operating crew and passengers?

In the fifth event, another low-flying helicopter carrying troops in a combat zone is shot at by an automatic small arms weapon. The helicopter is hit by several bullets, but survives the attack with minimum damage due to its low vulnerability design. It continues on its mission with some minor aircraft damage, but no aircraft kill. However, three of the troops in the passenger cabin were hit by the gunfire, however; one was killed and two were wounded. Which discipline has the responsibility to prevent or mitigate this event and to protect the operating crew and the passengers?

In the final event, number six, another low-flying helicopter carrying troops in a combat zone is shot at by several automatic small arms weapons. The helicopter is hit many times, loses the ability to fly with control as rotor blades break, and crashes. A fire starts, and many of the occupants are killed either by the impact with the ground or the subsequent fire. Which discipline has the responsibility to prevent or mitigate this threat-caused event and to protect the operating crew and the passengers before and after the aircraft impacts the ground? (Table 1 summaries the six events)

To help identify the discipline responsible for all possible events, consider the following definitions for three general categories of events consisting of an aircraft loss or fatal injuries to the occupants of the aircraft. These event categories were developed by the Joint Aircraft Survivability Program (JASP) to categorize all actual combat incidents that resulted in an aircraft loss or occupant fatality (see Figure 1).

- Combat hostile action covers any Class A mishap (loss of aircraft or fatal injuries to the crew/passengers) caused by a threat weapon; this includes aircraft evading the threat, destroyed in place, or deemed irreparable..
- Combat non-hostile covers any Class A mishap occurring within a recognized combat theater of operations in which the loss of aircraft or fatal injury to the crew/passengers is not a direct result of a threat weapon.

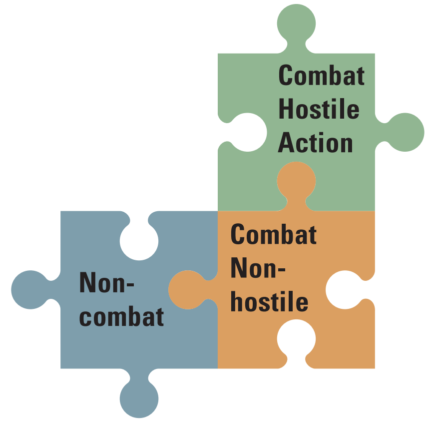

Figure 1: Event Categories (courtesy of JASP)

- Non-combat events cover Class A mishaps occurring outside a recognized combat theater of operations.

Note in Table 1 that the pertinent discipline can be relatively easily identified in only two of the six events. To determine the specific discipline responsible for the remaining four events, more information about the specific coverage of these disciplines is needed. Consequently, the SS discipline and the ACS discipline are briefly described below. The HSI discipline will be described in Part 2 in an upcoming issue of the Aircraft Survivability Journal.

SYSTEM SAFETY

System safety, the oldest of the three disciplines involved in the design of military aircraft for vehicle and occupant safety and survivability, attempts to eliminate, minimize, or control those conditions known as hazards that can lead to a mishap. Hazards are described in MIL-STD-882E as:

"A real or potential condition that could lead to an unplanned event or series of events (i.e., mishap) resulting in [unintentional] death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment. [2]"

Event	Environment	Cause	Outcome	Category	Discipline
#1	Normal	Engine fan blade failure	Aircraft loss & occupants killed in crash	Non-combat	SS
#2	Combat	Engine fan blade failure	Aircraft loss & occupants killed in crash	Combat non-hostile	?
#3	Combat	IR SAM hit	Aircraft killed & pilot ejects	Combat hostile action	ACS
#4	Combat	Power lines (while avoiding detection by an active threat)	Aircraft loss & occupants killed in crash	Combat hostile action	?
#5	Combat	Gunfire	Occupant killed due to gunfire	Combat hostile action	?
#6	Combat	Gunfire	Aircraft loss & occupants killed in crash	Combat hostile action	?

Table 1: Event parameters

Hazards result from internal system hardware and software failures, poor human interface designs, operator errors, or by outside influences, such as those environmental factors associated with the natural hostile environment. They are eliminated, minimized, mitigated, or controlled by design, a safety device, a warning device, or training. In summary, the SS discipline is responsible for preventing or mitigating event(s)/mishap(s) that result in the unintentional injury or death of the occupants and/or unintentional damage to or loss of an aircraft while the aircraft operates in either the normal and combat environment.

Damage caused by enemy weapons is not considered in system safety since the threat-caused damage is intentional.

AIRCRAFT COMBAT SURVIVABILITY

Aircraft combat survivability began its development as a design discipline during the Vietnam conflict over 40 years ago, when approximately 4,000 U.S. fixed –and rotary-wing aircraft were lost in combat. (An additional 4,310 aircraft were lost due to mishaps in theater—*i.e.,* combat non-hostile events.). ACS is dedicated to enhancing the capability of an aircraft to survive while operating in a combat or man-made hostile environment, where the damage or loss of aircraft and the death or injury of the occupants is intentionally caused by the enemy.

Aircraft combat survivability is comprised of two components: susceptibility and vulnerability. Susceptibility is the inability of an aircraft to avoid hits by the damage mechanisms carried or generated by warheads on the enemy's weapons, such as ballistic projectiles from guns, or fragments and blast from internal or external detonation of high explosive (HE) warheads. Vulnerability is the inability to withstand any hits by the projectiles, fragments, and blast that do occur. [1]

The primary focus of ACS has been on designing aircraft to be more survivable in combat, as opposed to the combined aircraft and occupant safety focus of SS, which is primarily concerned with the non-combat and combat non-hostile flight environments. The ACS aircraft-centric concentration on keeping the aircraft flying while operating in a man-made hostile environment does not mean there is no consideration given to any of the occupants. Those aircraft occupants that are essential to the continued controlled flight—or survival—of the aircraft (*i.e.,* the operating crew), must be protected from death or serious injury if the aircraft is to survive.

For example, the single pilot on the close-air support A-10 Thunderbolt II, or Warthog, sits inside a heavy titanium armor tub to protect him or her from ballistic projectiles or warhead fragments that hit the aircraft in the pilot's vicinity. The armor tub under and around the pilot was not put there by a safety engineer to enhance the pilot's safety; bullets and fragments are not considered safety hazards because they are not unintentional. They were put there by a vulnerability reduction engineer to protect the pilot, and hence enhance the aircraft's combat survivability by preventing a critical component (the pilot) from being killed by a bullet or fragment.

However, there is a great deal of overlap between designing for system safety and designing for combat survivability. There are many design features on an aircraft that simultaneously enhance safety and survivability, or more specifically reduce vulnerability. Consider the hydraulic subsystem on an aircraft. Failure of a hydraulic seal due to a material defect (safety) or fragment hit (vulnerability) could lead to a sequence of possible effects: 1) the flammable hydraulic fluid leaks from the failed or "killed" hydraulic seal onto a hot surface, 2) the fluid ignites, 3) the subsequent hydraulic fluid fire burns through the single data bus carrying a bundled set of control signals to the surface actuators at the tail of the aircraft, 4) the pilot loses control of the aircraft, and 5) the aircraft crashes.

This safety hazard could be minimized at an acceptable cost by design (replacing the flammable fluid with nonflammable fluid and moving the control signal lines or adding a second, separated control path for redundancy), by adding a safety device (installing fire detection and extinguishing equipment near the actuator), by adding a warning device (a fire light in the cockpit to alert the pilot of the emergency condition), and by training (the pilot practices emergency fire procedures). Note that all of these features control the hazard and also reduce the vulnerability of the aircraft by increasing its capability to withstand the combat (man-made) hostile environment. In other words, the hydraulic subsystem is now both safer and less vulnerable to a leak, regardless of whether the leak was caused by a part failure (SS) or a threat warhead fragment (ACS). [1]

Not every safety feature enhances combat survivability, however, unless it is also designed to do so. For example: Redundant hydraulic power sources are a safety feature, regardless of their location. They are also a combat survivability feature, but ONLY when there is sufficient separation between the redundant power sources so that a single hit by a threat weapon, such as an internally detonating 23-millimeter HE projectile, does not kill all redundant power sources. Furthermore, many safety features are limited in their ability to control hazards when an aircraft is hit by an enemy weapon, particularly those with high explosive warheads.

Simultaneous failures of multiple unrelated systems is possible with aircraft combat survivability, but not typically considered with system safety. Additionally, the concept of cascading damage, where one hit component causes other nearby components to fail, potentially overwhelming installed safety features, plays a major role in combat survivability.

An example of likely insufficient safety features in the non-combat environment was TWA 800, a 747 that apparently had a spark-caused major explosion in the mid-wing fuel tank, resulting in the total loss of the aircraft. After this incident, an onboard inert gas generating system was proposed for airliner fuel tanks to reduce the likelihood of a fuel tank explosion. In this case, the redesign of the aircraft for improved safety involved the use of a combat survivability design feature used on military aircraft.

An example of cascading damage from a non-combat event similar to what might be seen in a combat is Air France 4590, a Concorde taking off from Charles de Gaulle International Airport on 25 July 2000. Shortly before rotation, the front– right tire of the left landing gear ran over a strip of metal and was damaged. Tire debris was thrown against the lower–left wing structure, leading to a ruptured fuel tank due to the hydrodynamic ram caused by the impact of the tire debris. A major fire ignited almost immediately and as the aircraft took off, indications of a fire alarm on engine 2 appeared and the crew shut down the engine. They noticed that the landing gear would not retract, causing significant drag on the aircraft in the heavily loaded takeoff configuration. The aircraft flew for around a minute at a speed of 200 knots and at an altitude of 200 feet, but was unable to gain further height or speed. Then engine one lost thrust, leading to a significant increase of the aircraft's angle of attack and bank. Then thrust on engines three and four fell suddenly.

As can be seen from this example, the Concorde did not have typical military survivability enhancement features for vulnerability reduction, such as sufficient hydrodynamic ram protection, an effective system to inert the fuel tank against an in-tank fire, or redundant engine controls routed with enough separation (or physical protection) such that a fire could not disable the engine control path.

EXPANDING THE SCOPE OF THE ACS DISCIPLINE

Historically, ACS has had an aircraft-centric view of survivability and force protection. This view is primarily driven by the assumption that if the aircraft continues to maintain the essential or critical flight functions (lift, thrust, control, and structural integrity), then all of the occupants on the aircraft are indirectly protected. This viewpoint is inherent in the definitions of the aircraft attrition kill levels (KK, K, A, and B), based on flying time after being hit. The recent conflicts in Iraq and Afghanistan, however, have shown many instances in which crew members and passengers have been killed or seriously injured, even though the damage to the aircraft did not reach attrition kill level. Event example number five is an illustration of that possibility. Consequently, to fully consider force protection for all of the occupants, casualties must be considered as a separate metric from aircraft attrition.

Because of the importance of force protection for all occupants and the need to reduce casualties from all potential sources, a recent framework has been developed to expand the scope of ACS to

Figure 2 Air France 4590 on takeoff

include consideration of all occupants on an aircraft flying in a man-made hostile environment, not just the crew that are essential for flight. [3] Recent efforts within the Department of Defense in the past several years to include comprehensive force protection requirements as part of ACS have been a key driver in addressing user casualties in survivability assessments as required by Section 2366, Title 10, of the U.S. Code. In particular, there has been an ongoing effort since 2007 to expand ACS to include occupant crash survivability, particularly for helicopters. Methodologies to evaluate crew casualties using the Computation of Vulnerable Area Tool and Advanced Joint Effectiveness Model have been implemented since 2010. The Director, Operational Test and Evaluation has also endorsed using force protection analysis methods in the development of the live-fire strategy for new programs. From an earlier *Aircraft Survivability Journal* article:

"The combat hostile action loss rate for (rotary-wing) aircraft in Operation ENDURING FREEDOM (OEF) and Operation IRAQI FREEDOM (OIF) was eight times lower than Vietnam, primarily because aircraft vulnerability reduction design reduced the 'cheap kills' caused by the small arms and automatic weapon threats.

The human fatality rate associated with combat hostile action (helicopter) losses also showed a reduction from Vietnam to OEF/OIF, but not to the same extent. Some of this decrease in the fatality rates can be attributed to having more survivable aircraft, but improvements in airframe crashworthiness and crash protection for passengers are necessary to further reduce fatalities and injuries." [4]

Also, members of the ACS community have been given instructions to: *"...broaden their scope and refocus their efforts, and to work in concert with the aircraft safety community to predict and reduce combat-related occupant (passenger and crew) casualties."* [4]

Note that broadening or expanding the scope of ACS to include all of the occupants (not just the flight essential crew) and crashes (which have historically been the responsibility of system safety) will involve a sharing of information, but not an overlap of responsibilities. However, it should be noted that at least one well-known military aircraft manufacturer tasks its vulnerability reduction personnel for enhancing crash survivability including the structures, fuel systems, and occupant-protection design teams. The sequence of events for the expanded aircraft combat survivability discipline begins with an assessment of the threats to the aircraft while it is operating in a man-made hostile environment and ends with an assessment of the aircraft's survivability and any crew and passenger casualties to the point of safe return or egress from the combat zone.

SURVIVABILITY AND FORCE-PROTECTION KEY PERFORMANCE PARAMETERS (KPPs)

Finally, consider the relationship between SS, ACS, and two of the mandatory KPPs for manned systems: survivability and force protection. These KPPs will have different emphases. Survivability KPPs should emphasize preventing a system kill, whereas force protection should emphasize preventing personnel casualties [5].

According to the Joint Capabilities Integration and Development System (JCIDS), survivability attributes are defined as:

". . . those that contribute to the survivability of a manned system. This includes attributes such as speed, maneuverability, detectability, and countermeasures that reduce a system's likelihood of being engaged [hit] by hostile fire [susceptibility reduction], as well as attributes such as armor and redundancy of critical components that reduce the system's vulnerability if it is hit by hostile fire [vulnerability reduction]." [6]

Because the survivability KPP is specifically applied to the manned aircraft as a system and addresses only the hostile fire threat associated with a combat (man-made) hostile environment, ACS is the pertinent system design discipline for the survivability KPP. Even though ACS has been broadened to include all aircraft occupants, it still retains all the inherent coverage of aircraft survivability .

Force-protection attributes are defined in JCIDS as:

". . . those that contribute to the protection of personnel by preventing or mitigating hostile actions [or threat effects] against friendly personnel, military and civilian. This may include the same attributes as those that contribute to survivability, but the emphasis is on protecting the system operator or other personnel rather than protecting the system itself. Attributes that are offensive in nature and primarily intended to defeat enemy forces before they can engage friendly forces are not considered force protection attributes. Attributes that protect against accidents, weather, natural environmental hazards, or disease (except when related to a biological attack) are also not part of force protection." [6]

The force-protection KPP applies to all occupants on an aircraft operating in a combat environment. The emphasis of the KPP is to address personnel casualties more broadly. A force-protection KPP might address tactics, techniques, and procedures (TTPs) or a system design feature that directly protects the crew [7]. In fact, the only aircraft survivability enhancement feature outside the scope of the JCIDS definition of the force-protection attributes is threat suppression, because it is typically offensive in nature and intended to defeat enemy forces before they can engage.

The other five susceptibility-reduction concepts (threat warning, signature reduction, expendables, tactics, and noise jamming and deceiving), although not emphasized, and the six vehicle vulnerability reduction concepts (component redundancy with separation, component location passive damage suppression, active damage suppression, component shielding, and component elimination/replacement) could be applied to show how personnel casualties are reduced. The difficulty when applying all of the susceptibility and vulnerability reduction concepts, with respect to the force-protection KPP, is to show how personnel casualties are directly reduced, and not just how they increase the survivability of the aircraft. If the historic aircraft-centric view of ACS were retained, it would be somewhat more difficult to define a force-protection KPP that is not also a survivability KPP.

For example, consider the armor tub installed on the A-10 aircraft. From an aircraft-centric view of ACS, the armor tub that protects the pilot (who is a critical component of the flight-control system) is a survivability enhancement feature of the aircraft, with force protection being incidental. From this perspective, and depending on the threat being evaluated, an aircraft designer could trade the weight of the tub and the protection it provides to the pilot for the ability to carry extra weapons or fuel, assuming the user is willing to accept any increased vulnerable area attributed to the pilot. However, from a force protection view of ACS, the armor tub fulfills a clear role: protecting the pilot from being killed or injured. Although other methods could be used to enhance vehicle survivability, such as including a second pilot (effectively separated from the other pilot), the aircraft designer may not be able to trade the tub for something else because the metric of crew casualties would still need to be evaluated.

Unfortunately, adding armor to protect occupants tends to be the default response when developing a force-protection KPP. This need not be the case. The predominant threat in the flight regimes of interest should drive the requirement.

For example, users could write a force-protection KPP to add armor in the cockpit of a large fixed-wing aircraft to protect pilots from being hit by small arms projectiles. At first look, this appears to be very clear requirement to

Figure 3: Concorde Crash

provide protection for personnel. However, since there is no requirement to put armor in the rest of the aircraft to protect the nonpilot crew and passengers, this is really a survivability KPP with the appearance of a force-protection KPP. In this instance, the purpose of the armor is to protect the pilots, who are considered critical components, with the rationale that killing both pilots will result in killing the rest of people on the aircraft. This rationale invokes the aircraft-centric view of ACS, which relegates the pilots, crew, and passengers to be either critical components or noncritical components, and accordingly noncritical crew and passengers are not protected.

This discrepancy becomes more acute if the aircraft only spends a small portion of its time at low altitude where small arms threats are prevalent. Looking across all flight regimes, maybe a better force-protection solution would be to add an emergency oxygen system such as the one used on commercial airlines when there is a sudden loss of cabin pressure. This emergency system could also protect against smoke and other toxic gases in the event there is a threat-induced fire in the cabin area. It would likely have the added benefit of weighing less than the armor. This emergency oxygen system would serve as both a safety feature to prevent loss of oxygen during a sudden depressurization and an aircraft survivability feature to provide an alternate oxygen source to avoid crew and passenger asphyxiation.

Finally, consider ejection seats installed in a jet aircraft or crashworthy seats installed in a helicopter. From the aircraft-centric perspective of ACS, neither would buy their way on the aircraft because they don't increase the survivability of the platform. However, from an expanded scope of ACS that includes force protection, both can be considered part of force protection because these features help save lives, even though the aircraft might be an attrition loss.

One might argue that the last sentence in the JCIDS description of the force-protection attribute would prohibit considering ejection seats and crashworthy seats because they protect against an accident (or mishap in the system safety vernacular). This is not the case; neither seat protects against the mishap. The mishap may occur regardless of whether the seat (ejection or crashworthy) is installed. The purpose of the seat is to protect its occupant—clearly a force-protection concern.

Additionally, the ACS discipline would need to address concerns such as the compressed timeline for a pilot to eject out of a severely damaged aircraft from combat hostile action, such as in internal detonating warhead leading to an explosion and immediate loss of aircraft structural integrity. This scenario would require that an ejection seat be built with features to ensure successful ejection under unique flight envelopes that would be outside of the normal flight environment.

IDENTIFYING THE RESPONSIBLE DISCIPLINES

Returning to the six examples of events shown in Table 1, now that the significant details of the SS and the expanded ACS disciplines and the survivability and force-protection KPPs have been described, a decision can be made as to which discipline is the primary discipline responsible for preventing or mitigating an event (see Table 2).

Consider event number two. Even though the event occurs in the combat environment, the cause of the event, a fan blade failure, is not threat related. Hence, SS is the applicable discipline.

Event	Environment	Cause	Outcome	Category	Discipline
#1	Normal	Engine fan blade failure	Aircraft loss & occupants killed in crash	Non-combat	SS
#2	Combat	Engine fan blade failure	Aircraft loss & occupants killed in crash	Combat non-hostile	SS
#3	Combat	IR SAM hit	Aircraft killed & pilot ejects	Combat hostile action	ACS
#4	Combat	Power lines (while avoiding detection by an active threat)	Aircraft loss & occupants killed in crash	Combat hostile action	SS & Expanded ACS
#5	Combat	Gunfire	Occupant killed due to gunfire	Combat hostile action	Expanded ACS
#6	Combat	Gunfire	Aircraft loss & occupants killed in crash	Combat hostile action	SS & Expanded ACS

Table 2: Event Parameters with Expanded ACS

In event number four, if the helicopter were flying low in a combat zone to avoid detection, then SS is again the appropriate discipline, because helicopters can fly low and into power lines in normal environments—not because of damage from a threat weapon. However, if the threat is fired at the aircraft (*i.e.,* an engagement occurs) and the aircraft flies into the wires while attempting to evade the approaching threat, then the loss is directly related to the aircraft's attempt to evade the threat. In this case the loss would be categorized as a combat hostile action loss, and ACS would be the appropriate discipline responsible for preventing or mitigating similar events in the future.

For event number four, the time when the event occurs—either before or after the threat engages the aircraft—determines the appropriate discipline. However, one might consider whether an aircraft attempting to avoid detection by an active threat, and a subsequent weapons engagement, blurs the lines of "before" (avoid detection) and "after" (engagement) categorization. Perhaps the loss of aircraft and crew were due to combat TTPs, poor threat warning system, inadequate signatures (IR, radar, acoustic) that required the aircrew to fly nap-of-the-Earth, or perhaps they experienced a loss of situational awareness due to certain wartime modes and sensors. The ACS contributions to reduce losses from a threat engagement are obvious, but clearly the SS and ACS communities must work together to enhance safety and survivability in this scenario.

In event number five, the aircraft-centric scope of ACS did not include protection of the passengers, and SS does not consider intentional threat-caused events. Thus, expanding ACS to include force protection for all occupants is a necessary action, particularly since ACS includes protection of those members of the force who are critical components.

In event number six, the cause of the crash is combat related, and therefore not within the purview of SS. However, aircraft also crash while flying in normal environments, which is in the purview of SS, so assigning crash survivability to the SS discipline is reasonable. On the other hand, the crash of an aircraft that has been severely damaged in combat can be significantly more catastrophic, so assigning the responsibility for crash survivability to the expanded ACS discipline is also reasonable. Therefore, once again, a shared view of both the SS and the expanded ACS discipline seems to be the best solution. Both disciplines need to share information and work to design optimized solutions to improve the survivability of the aircraft and the survivability and safety of personnel on board.

RECOMMENDATIONS AND SUMMARY

Five recommendations are provided below to facilitate the transition of the expanded ACS discipline from policy to common practice. The ability to address all potential combat-related casualty sources can be achieved by taking a number of steps from several organizations, including:

- Introducing the expanded force protection coverage into future ACS educational programs and forums
- Funding technology for reducing occupant casualties in combat
- Refining the methodology for assessing the level of occupant protection in combat
- Testing for occupant protection
- Working with the requirements community to coordinate responsibilities between the SS, ACS, and HSI disciplines.

In summary, the scope of the ACS discipline now includes comprehensive force protection as a matter of policy. This would also include combat-related crash survivability for all occupants on an aircraft, not just the crew that are critical to flight of the aircraft. Furthermore, ACS should work in concert with the SS discipline to achieve force-protection synergy in the design of the aircraft for all flight environments.

The second part of this article will describe the domains of the HSI discipline and examine how these domains interact with those of SS and the expanded ACS, especially as they relate to enhancing aircraft survivability and force protection.

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ASJ

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