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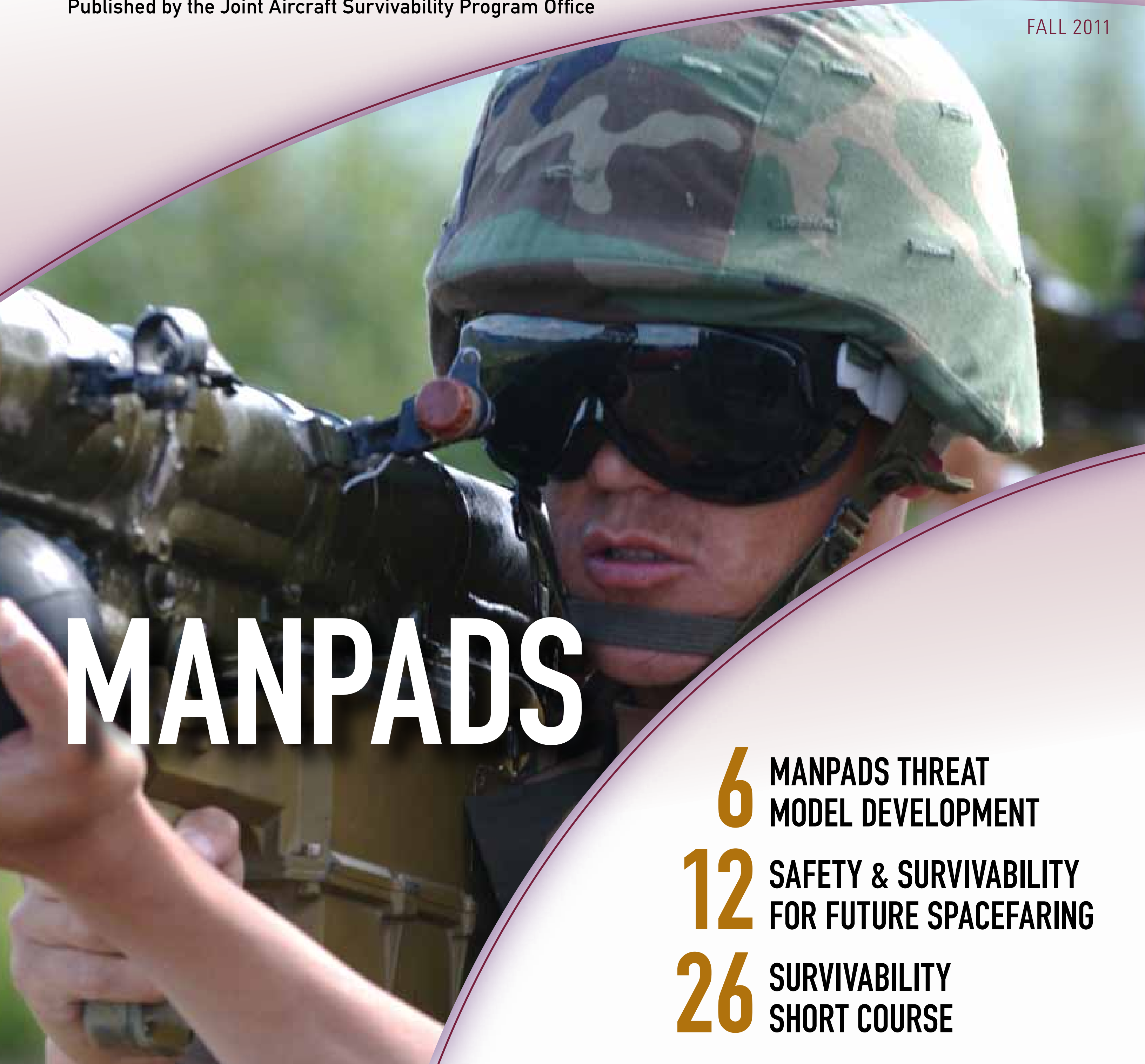

MANPADS

Report Documentation Page

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On the cover:
Munkhuu Batmunkh, Mongolian Air Defense Force, practice aims an SA-7 Man-portable air-defense systems (surface to air missile launcher) on the Pacific Alaskan Range Complex on July 16 during Red Flag-Alaska 07-3.

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Man-Portable Air Defense Systems (MANPADS) represent a significant threat to both military and civilian aviation. Military strategic, tactical, and transport aircraft, as well as commercial transport aircraft remain susceptible to MANPADS for a variety of reasons. Recent events have raised the level of awareness of this threat and the need to counter it.

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by Robert E. Ball

As we move to the next generation of manned spacecraft, new initiatives would benefit from combining the survivability concepts of military aircraft design with the safety discipline of the spaceflight community.

16 Excellence in Survivability—William Keithley
by Eric Edwards

The Joint Aircraft Survivability Program (JASP) is pleased to posthumously recognize Mr. William Keithley for Excellence in Survivability.

18 V_{50} versus V_0 Armor Measurements and Modeling
by Jim Rhoads

As defined in MIL-STD-662F, a material's Ballistic Limit (or V50) is "The minimum velocity at which a particular projectile is expected to consistently, completely penetrate armor of given thickness and physical properties at a specified angle of obliquity. The ballistic limit is the maximum velocity at which a particular projectile is expected to consistently fail to penetrate armor of given thickness and physical properties at a specified angle of obliquity.

20 Aircraft Survivability for Counter-insurgencies

by Nicholas Hardman

Current U.S. military aircraft were designed and acquired based on a paradigm of war very different than those currently being waged in Afghanistan and Iraq. So how have our aircraft fared in counter-insurgency (COIN) operations, and what revisions to survivability requirements are implied by the results?

23 Aircraft Combat Reporting – Forward Deployed Success

by David Mullins

During Operation Enduring Freedom and Operation Iraqi Freedom (OEF/OIF) a joint group of Reserve Air Force, Marine Corps, Navy and Army personnel were deployed to Iraq to begin the process of data gathering on aircraft damaged in combat. This was the first full time deployment for the Joint Combat Assessment Team (JCAT). Overall, the mission to collect battle damage data began during the Vietnam Conflict. Since its inception in December of 1984, the Survivability Information Analysis Center's (SURVIAC) mission has included the collection of combat damage data, and since that time has accumulated over 30,000 incident reports spanning the past 50 years of conflict.

24 Dale Atkinson Receives Arthur Stein Award

by Lowell Tonnessen

On 7 June 2011, the Test and Evaluation (T&E) Division of the National Defense Industrial Association (NDIA) presented Mr. Dale Atkinson with the Arthur Stein Award for outstanding contributions in live fire test and evaluation (LFT&E). The award was given at the organization's LFT&E Conference at Eglin Air Force Base, FL.

26 Survivability Short Course

by Chris Adams and Mark Couch

The 2011 Joint Aircraft Survivability Program (JASP) Short Course was held 17-20 May at the Naval Postgraduate School (NPS) in Monterey, CA. 52 students attended the course, including military, civilian, and contract employees working for Department of Defense, industry, and academia. The lead instructors were Chris Adams, Director of the Center for Survivability and Lethality at the NPS, and Dr. Mark Couch, Research Staff Member at the Institute for Defense Analyses.

28 USAF Combat Damage Incident Reporting: Improving the Process

by Richard Huffman, Jr. and Chris Jerome

In the US Air Force, changes in organization and doctrine which embrace the Aerospace Expeditionary Force (AEF) construct have had some unintended consequences. One of these consequences is the omission of contemporary aircraft battle damage information from historical records.

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News Notes

by Dennis Lindell

Demonstration Flight of the Advanced Distributed Aperture System (ADAS)

Dennis Lindell and Robert Lyons from the Joint Aircraft Survivability Program Office (JASPO) participated in a 30-minute demonstration flight of the Advanced Distributed Aperture System (ADAS). ADAS is a USSOCOM FY08–FY10 Joint Capabilities Technology Demonstration (JCTD) project led by the US Army Night Vision and Electronic Sensors Directorate (NVESD) at Ft Belvoir, VA. Over the last couple of years, NVESD has been demonstrating to operators and decision makers an ADAS installed aboard an H-60 Blackhawk helicopter.

The ADAS is a multi-spectral distributed aperture day/night viewing system, consisting of six cameras mounted on the outside of a helicopter. Imagery from each camera is processed and stitched together, projected onto the visor of each Helmet Mounted Display (HMD), and provides each aircrew member with an independent, unrestricted view around the aircraft. Capabilities for hostile fire detection, landing in brown-out conditions and other navigational functions have been demonstrated.

Frank Barone Retires

After 32 years at the Naval Research Laboratory, Dr. Frank Barone retired from government service this July. Frank has been instrumental in the success of the Joint Aircraft Survivability Program (JASP) through his exemplary leadership, technical insight and common sense approach. Frank has been an active JASP committee member since 1989, including serving as committee chair of the Susceptibility Reduction subgroup since 2002. An internationally recognized expert that "tells it like it is and gets the job done," Frank will be missed by the JASP community and we wish him well in his new pursuits.

Welcome CDR Jimmy Choi to JASP

CDR Jimmy "Steamer" Choi is the newest addition to JASP. He checked aboard August 2011 as the JASP Military Deputy Program Manager. Jimmy is a Navy representative from NAVAIR. He is a 2011 graduate from the Naval Postgraduate School where he earned his MBA in Financial Management. Jimmy earned his BS in General Science from the United States Naval Academy.

Upon graduation from the Naval Academy, Jimmy was assigned to the Rotary Test Wing in Patuxent River, MD as an assistant project officer. Following his tour he reported to Pensacola, FL where he began his flight training and earned his wings as a Naval Flight Officer. CDR Choi's first operational tour was with VS-24 flying the S-3B Viking where he made deployments aboard the USS Theodore Roosevelt and USS Enterprise. It was there that he participated in Operation Noble Anvil in Kosovo and Operation Southern Watch over Iraq.

Following his tour with VS-24, he was selected as the Flag Aide to the Deputy Commander of Naval Forces Central Command. Upon completion of his Aide tour, Jimmy transitioned to the E-2C Hawkeye. His operational assignments included a tour with VAW-126 aboard the USS Harry S. Truman in support of Operations Enduring and Iraqi Freedom, and a tour with VAW-121 aboard the USS George Washington and USS Dwight D. Eisenhower. After completing his fleet tours, Jimmy volunteered as an Individual Augmentee to US Central Command as a J-5 planner in the Afghanistan/Pakistan branch.

Please join us in welcoming Jimmy to the Joint Aircraft Survivability Program.

LFT&E Conference Held at Eglin AFB in June

On 7–9 June 2011, about 100 live fire test and evaluation (LFT&E) professionals from across the country convened at Eglin Air Force Base, FL, for the National Defense Industrial Association's (NDIA) ninth LFT&E Conference. The keynote address was delivered by Mr. Richard Sayre, who serves as Director, Live Fire Testing in the Office of the Director, Operational Test and Evaluation (DOT&E), Office of the Secretary of Defense. Mr. Sayre

Continued on page 29

JCAT Corner

by Lt Col Norman White, USAF, Lt Col Jeffrey Ciesla, USAF, and Lt Col Charles Larson, USAF

The Joint Combat Assessment Team (JCAT) continues to supply essential hands-on support for our warfighters in Afghanistan, while providing analysis and training in CONUS. On the training side, the Navy contingent of the JCAT expertly organized and hosted this year's Threat Weapons and Effects Seminar (TWE) at Hurlburt Field – Eglin AFB, FL, during April. This annual seminar is a joint effort between the JCAT—which is sponsored by the Joint Aircraft Survivability Program (JASP)—the USAF Aeronautical Systems Center (ASC), Naval Air Systems Command (NAVAIR), Defense Intelligence Agency (DIA), the Missile and Space Intelligence Center (MSIC), and other agencies. The intent of this seminar is to provide a comprehensive overview of threat lethality, with a focus on the lethality of threat air defensive systems and the damage these systems inflict to our aircraft. Real-world intelligence briefings, coupled with information garnered from threat exploitation, generate a factual overview of current trends that the warfighter is currently confronted with. Hands-on experience is provided through the use of example threat munitions, test articles, damaged aircraft hardware, and videos from actual combat incidents. The seminar culminated with a live-fire demonstration of Man Portable Air Defense Systems (MANPADS) and Rocket Propelled Grenades (RPG). Drawing from comments from the 200+ attendees, it was a complete success. Special thanks to LCDR Shawn Denihan and his team for an outstanding job!


Capt Cody Gatts


Capt Dan Carroll


Lt Colonel Greg Moster

Two new USAF JCAT members entered Afghanistan this spring. Capt Cody Gatts is currently deployed to Kandahar Airfield, Afghanistan. Although he is utilized in any part of the AOR, his duties include assessing all combat damage to aircraft that occurs in Kandahar Province, Uruzgan Province, Zabul Province, and Day Kundi Province. Capt Gatts brings an aerospace engineer's perspective to the team, whereas many of our professionals have flight operations backgrounds. Our other new Air Force deployer, Capt Dan Carroll, is deployed to Bagram AB assessing aircraft weapons effects damage. After graduation from the USAF Academy, Capt Carroll gained extensive experience in missile operations – bringing a much needed missile operations/understanding perspective to JCAT. In addition, prior to his deployment, Capt Carroll was an engineering instructor at the USAF Academy. While in that capacity, he served as Deputy Director of the Center for Aircraft Structural Life Extension (CAStLE), which brings up-to-date metal fatigue/damage analysis techniques to the JCAT community. We welcome both of them. Currently, OIC for JCAT in Afghanistan is Navy CDR Daniel Boscola. Joining him in representing the Navy is LT Khan Luu. All are diligently working together in this extremely busy theater of operations.

Finally, in June, we bid a fond farewell to one of the most experienced JCAT members. Lt Colonel Greg Moster retired after 28 years USAF service, bringing an end to a long and fruitful career. As one of the first JCAT officers in the modern era, Greg instituted many unique techniques and procedures to the JCAT arena. In fact, many of the forensic techniques currently used were pioneered and developed by Lt Col Moster. Also, Greg was instrumental in making JCAT a true "Joint" organization, working hand-in-hand with the Army, Navy and Marines for continual advancement of combat forensics. Hence, Greg's influence will be continued and taught through future operations for generations of JCAT assessors. Greg won't be far away, though, working as a civilian for Air Force Research Laboratory (AFRL) here in Dayton – we will be able to tap his experience as needed. God Speed Greg. ■

MANPADS Threat Model Development

Characterization of Static and Dynamic Blast, Fragmentation, and Missile Body Debris

by Greg Czarnecki, Stan Loughmiller, John Valek, Tim Grose, and John Haas

Man-Portable Air Defense System (MANPADS) represent a significant threat to both military and civilian aviation. Military strategic, tactical, and transport aircraft, as well as commercial transport aircraft continue to remain susceptible to MANPADS for a variety of reasons. Recent events have raised the level of awareness of this threat and the need to counter it.

Investment decisions to counter the MANPADS threat require an understanding of likely engagement outcomes. The key question is, "what is the potential for an aircraft kill given a hit?" We need to obtain answers to more fundamental questions in order to answer this question. What is the extent of warhead blast damage that might be sustained by an aircraft? What is the extent and depth of warhead fragmentation and missile body debris penetration that might be sustained? Answering these questions requires credible threat models supported by high-fidelity test characterizations of the MANPADS missile threat. Based on concerns over Blue aircraft survivability, the Joint Aircraft Survivability Program combined forces with the Joint Live Fire – Aircraft Systems Program to generate the necessary blast, fragmentation, and body-debris data. The 46th Test Group (46 TG) at Wright-Patterson AFB directed and coordinated the overall effort. The Army Research Laboratory (ARL) had responsibility for all static (non-moving) threat characterization tests. The Naval Air Warfare Center (NAWC) had responsibility for all dynamic (moving) threat characterization tests. Direct involvement of the Aeronautical Systems Center, NAWC, and ARL also yielded necessary coordination with the modeling and simulation community to provide threat data requirements and to ensure test data transition into the threat models.

While some threat characterization data have been developed for common MANPADS threats, high-fidelity reliable data have not been developed to the modeling community's satisfaction. Past efforts have rarely taken care to obtain detailed test data. Such is the charge of the present effort whereby high-fidelity static and dynamic MANPADS blast, fragmentation, and missile body debris data are being obtained. Modelers required blast pressure time histories as a function of small azimuth changes (angles off the missile's nose) and small near-field radii differences while considering the missile's dynamic motion at the moment of detonation. Similarly, complete threat model assembly requires warhead fragment and missile body debris distribution and detailed velocity information.

The goal of the overall test series (static and dynamic assessment of warhead blast, fragmentation, and missile body debris) is to yield data of sufficient accuracy and precision to improve the accuracy of MANPADS threat models used in aircraft vulnerability assessment codes. These codes include Computation of Vulnerable Area Tool (COVART), the Advanced Joint Effectiveness Model (AJEM), as well as damage prediction and assessment tools such as LS-DYNA and the Combat Assessment Tool (CAT) that together support aircraft acquisition program offices and the warfighter. The unique nature of the required high-fidelity tests will also establish a protocol for future evaluation of other similar MANPADS threats and small warhead munitions. Modelers requested specific data improvements, including:

1. Increase the capture of overall missile mass. Attempt to improve mass capture from the present 5-15% to nearly 40%.
2. Quantify masses and velocities of missile body debris. Seldom achieved in previous tests.
3. Capture all fragment masses that penetrate the catch bundles. Previous tests often ignored collection of the smallest of fragments.
4. Map fragment and debris masses to their velocities. Never achieved with any level of fidelity. Previous tests captured sample/average velocities and assigned these velocities to large numbers of fragment masses.
5. Refined measurements of side-on (static) blast pressures over azimuth angles. Seldom achieved over small azimuth angles to define blast asymmetries.
6. Refine measurements of face-on (stagnation) blast pressures over azimuth angles. Seldom achieved over small azimuth angles to define blast asymmetries.
7. Refine measurements of side-on blast pressures over near-field radii. Seldom achieved over small near-field radii to define blast asymmetries.
8. Eliminate blast reflections prior to data capture. Ensure sufficient warhead height above the ground.
9. Assess the influence of rocket motor fuel presence on blast and fragmentation. Rarely investigated to assess differences on the test outcome.
10. Assess moving-missile effects on the test outcome. Rarely investigated with precision.

Conventional test processes needed significant improvements in order to provide the required data fidelity. Tall arena walls were set up 360° around and in close proximity to the missile to achieve 44% mass capture (a marked improvement over previous test attempts that captured 5–15% mass).

The entire missile was placed in the arena to ensure maximum characterization of the often-ignored, but highly damaging, missile body debris. The test carefully extracted all fragments from the catch bundles that were in excess of 4 grains (a marked improvement over previous test attempts where such small fragments, capable of damaging aircraft wire bundles, hydraulic lines, and avionics, were often dismissed). The test paid maximum attention to mapping masses to their velocities, whereas previous test attempts rarely achieved any mass-velocity mapping. Side-on pressure gauges were maximized in number, and supplemented with face-on gauges to fully-quantify blast asymmetries and near-field pressure degradation as a function of radius. Previous test attempts used few sensor positions and with sensor placements that were relatively far-field. The missile was positioned sufficiently high off the ground and away from reflective surfaces to allow full and unambiguous recording of the incident blast wave before reflections impinged on the sensors. Some tests were performed with a partial load of rocket motor fuel (absent or undefined during previous test attempts) to assess any influence on the test outcome that would warrant a variation to the missile model. And lastly, some static tests were replicated dynamically to allow first-ever 1:1 correlation between MANPADS static and dynamic datasets. This required that static and dynamic missile configurations be nearly identical while remaining true to the operational equivalent. The testers were interested in discovering if static fragmentation and blast fields a) are appreciably different from the corresponding dynamic fields and b) can be simply vectored forward to yield equivalent dynamic data. There was some concern that the bow-wave off the moving missile's nose might yield a reflective surface for the blast wave and result in a significantly different blast field. It was also possible that the static arena test would inaccurately predict the effect of missile body debris, which caused concern since large debris is expected to behave aerodynamically different if the missile is launched into the arena.

MANPADS Blast Characterization

MANPADS blast characterizations consisted of six static tests conducted by ARL at Aberdeen Proving Ground and two identically-configured dynamic tests conducted by NAWC at China Lake. All tests used full-up actual missile hardware to include the seeker, guidance and control, warhead, and rocket motor body sections. All tests also had the missile positioned horizontally at the moment of detonation. Dynamic tests were achieved within a blast-instrumentation arena that was identical to that used during static tests. In these dynamic tests, missiles were launched with precision (to include a controlled velocity) into the arena center using a gas-gun. Figure 1 shows the missile configuration for gas-gun launch. The missile had to be threaded into the arena, with only inches of clearance from the surrounding instrumentation, and then detonated exactly at the arena's center. Figure 2 shows the precision by which the missile had to enter the arena to clear instrumentation on the right and left by as little as 3 inches.

Before every test, all sensors were placed precisely. The test engineers were also careful to ensure all pressure gauges, many as close as 12" to the warhead centroid, were able to record blast while avoiding fragmentation damage. The following criteria established the credibility of the blast dataset:

1. Pre- and post-tests with C4 explosive to verify test instrumentation responses were in correlation with modeled test predictions,
2. observation of right-left blast symmetry within the arena, and
3. test-to-test repeatability of blast results.

Figure 2 Missile proximity to instrumentation when detonated

MANPADS Fragmentation/ Debris Characterization

MANPADS fragmentation/debris characterizations consisted of two static tests performed by ARL and two identically-configured dynamic tests performed by NAWC. All tests used full-up actual missile hardware to include the seeker, guidance and control, warhead, and rocket motor body sections. Missiles were positioned horizontally in the center of the static test arena (Figure 3). In order to achieve dynamic tests, missiles were launched with precision into the test arena that was the effective-equivalent of that used during the static tests. Again, for dynamic tests, gas-guns launched missiles into the arena center at a controlled velocity. Detonation occurred when the warhead was in the exact center of the arena. Quantification of fragmentation velocities were obtained by assessing the time-of-flight differences between warhead detonation and impacts on the adjacent arena walls. Fragments that passed into the arena walls were later extracted for weight and geometry measurements as well as velocity mapping.

Specialized instrumentation for the test arenas included tiled make-screens, used in combination with hundreds of data channels, to maximize fragment-velocity mapping. These make-screens were applied across the entire surface of the

Figure 1 Example Missile Configuration for Gas-Gun Launch

Figure 3 Missile Positioned in the Center of the Static Test Arena

Figure 4 Stream of Data Flowing to the Instrumentation Shelter at ARL

arena walls and reacted to every fragment passage. Dimensions of each make-screen tile were influenced by the expected fragment size as well as the density of adjacent fragment impacts. Areal dimensions of the make-screens ranged from 1–4 sq ft and were positioned such that no make-screen would receive more than a few fragment hits on average. So, rather than having tens or hundreds of fragment hits per zone where an average fragment velocity would be assigned to the entire cluster of fragments, small make-screen tiles provided an added fidelity whereby average velocities were assigned to each small group of fragments (where groups numbered in the hundreds). The test based the credibility of the warhead fragmentation and body debris dataset on:

1. Assessment of the fragment size distribution (which was expected to conform to a Mott distribution),
2. right-left symmetry of the fragment spray, and
3. test-to-test repeatability.

The Path Forward

Data generated during the static and dynamic MANPADS blast and fragmentation/debris tests yielded a significant improvement in test data fidelity that will be used to update missile threat models within COVART, AJEM, and LS-DYNA. Modelers will then apply the updated threat models to predict missile penetration and damage to a simple multi-plate array. The multi-plate array will be fabricated and subjected to dynamic MANPADS impact (Figure 5). Blast and fragmentation damage, together with the extent of penetration, will be quantified and then correlated with modeled predictions to establish missile model credibility. Once the missile models are proven credible, they can be applied to vulnerability assessments in support aircraft acquisition program offices engaged in Live Fire Test and Evaluation. The prescribed high-fidelity approach to MANPADS missile blast/fragmentation characterization also serves as a model for future exploitations of small munitions. ■

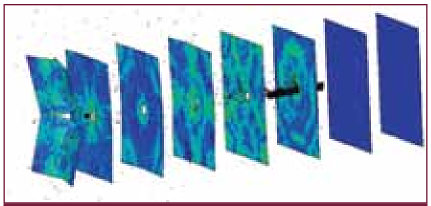

Figure 5 Predictions of Missile Penetration into Multi-Plate Array

Large Engine Vulnerability to MANPADS

by Greg Czarnecki, Joe Manchor, Gautam Shah, and John Haas

Large wide-body military and commercial transport aircraft continue to be attractive targets and are particularly susceptible to Man-Portable Air Defense Systems (MANPADS) during takeoff and landing due to large infrared emissions, slow speeds, predictable flight paths, unencrypted air traffic communications, and publicly available commercial schedules. The following model-test-model approach will study these vulnerabilities in order to discover ways to counter the threat of MANPADS.

An important first step in making investment decisions to develop and implement susceptibility and vulnerability reduction measures necessary to counter the MANPADS threat is to understand and determine the likely outcome of a MANPADS missile encounter with a large transport aircraft. The body of analysis and combat data has revealed that the most likely impact point for a MANPADS is on an aircraft's engine. However, given a hit on the engine, it is not clear what the level of damage will be and whether this damage will result in collateral effects that lead to loss of the aircraft. Open questions include:

1. What is the inherent vulnerability of large turbofan engines hit by MANPADS along likely shotlines?
2. What is the expected extent of engine damage?
3. How will damage affect engine operation and thrust?
4. What collateral damage might be sustained by surrounding aircraft structure and systems, such as the pylon, wing, hydraulics, or flight controls?
5. How will engine and/or collateral damage affect the aircraft's controllability and maneuverability for safety-of-flight?
6. Will damage produce an aircraft kill, and if so, what is the kill mechanism? And
7. What is the credibility of predictive models for engine-MANPADS engagements?

To answer the above questions, the 46th Test Group (46 TG) at Wright-Patterson AFB, OH, teamed with the Naval Air Weapons Center (NAWC) at China Lake, CA, and NASA Langley Research Center in Hampton, VA, to construct a building block model-test-model approach (see Figure 1). The emphasis in Phase I was to develop an engine-MANPADS modeling procedure suitable for high-fidelity damage predictions and in evaluating the procedure against live and inert MANPADS impacts on a non-operating TF39 (C-5 aircraft) engine. Testing and modeling continued during Phase II with live and inert MANPADS impacts on rotating engine disks to assist with risk reduction prior to full-up engine testing. Culmination of the overall engine-MANPADS effort is now underway whereby live MANPADS missiles will be launched into operating CF6-50 engines typical of KC-10, B747, B767, and A300 aircraft. This last stage (Phase III) of engine-MANPADS testing and modeling is the focus of the present discussion. The objective is to investigate large aircraft engine vulnerability to the MANPADS threat as well as safety-of-flight issues that result when the engine is hit. Goals include 1) assessing MANPADS damage effects on a rotating engine, 2) validating the engine-MANPADS modeling procedure, 3) assessing the engine's reaction to missile impact to include the potential for engine uncontainment and collateral damage, 4) assessing the potential for an onboard engine fire, and 5) assessing aircraft safety-of-flight given a MANPADS hit on the engine and collateral damage to surrounding aircraft components. The effort is co-sponsored by the Joint Live Fire (JLF) Aircraft Systems Program, the Department of Homeland Security's (DHS) Counter-MANPADS Program, and the USAF's Large Commercial Derivative Aircraft (LCDA) Program.

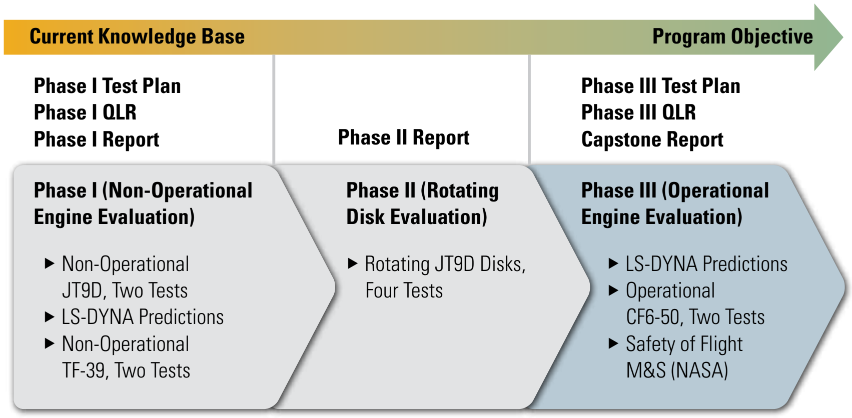

Figure 1 Engine-MANPADS Building Block Approach

Figure 2 CF6-50 Engine Mounted on Test Stand

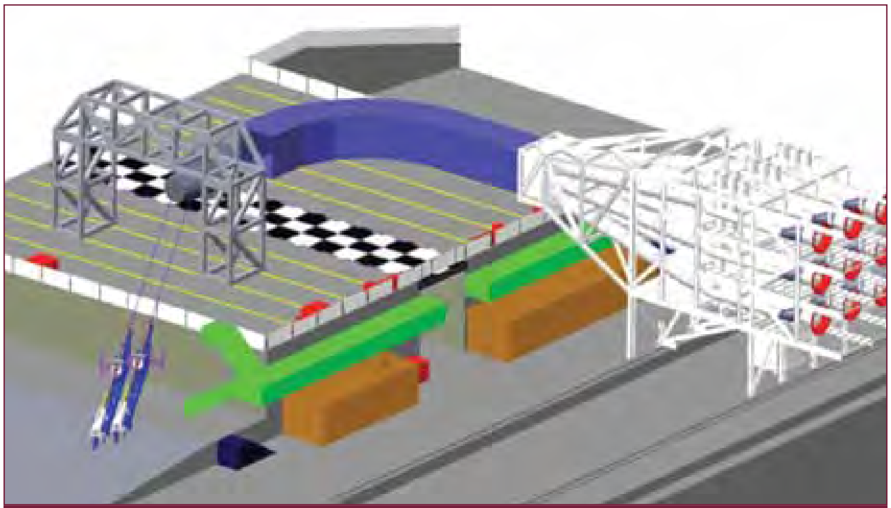

Figure 3 China Lake LFT Range Setup and Airflow Arrangement

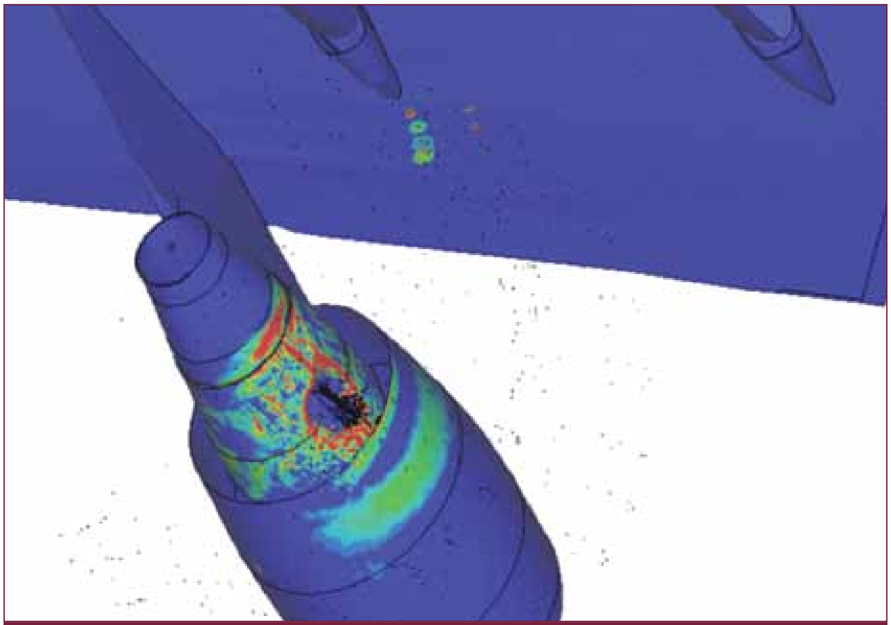

Figure 4 LS-DYNA Simulation of MANPADS Impact on a Large Turbofan Engine

Key roles and responsibilities during the Phase III operating engine evaluation are as follows: The 46 TG is overall project lead and is responsible for the engine-MANPADS test plan; supplying engine, cowling, and pylon test articles; preparing the engine control unit; designing and fabricating the steel engine support fixture (Figure 2); designing and fabricating witness panels that will surround the engine during test; conducting fit-and function tests to include verifying engine operation; instrumentation of the test articles and test fixture; shipment of test hardware to China Lake; contracting to General Electric for generation of damage predictions and consultation concerning engine operation; test direction; damage assessment with assistance from General Electric, the Joint Combat Assessment Team, and an Aircraft Battle Damage Repair team; and preparation of quick-look and final reports for the project. NAWC is responsible for test fixture assembly, test conduct (Figure 3), and data reduction; and NASA is responsible for post-test assessment of aircraft safety-of-flight, given collateral damage from a MANPADS hit on the engine.

Test articles consist of two General Electric CF6-50 turbofan engines, each combined with a Boeing B747 nacelle and outboard pylon. The test scenario involves a large aircraft climbing through an altitude of 6,000 feet at 225 knots when the engine is hit. The engine will be operating at a climb-out power setting (approximately 86%), generating a thrust of 46,000 lbs. Engine impact locations are based in part on MANPADS endgame analysis performed by the 46th Test Wing's Guided Weapons Evaluation Facility (GWEF) on both the C-5 (sponsored by the C-5 program office) and the Boeing 747 (sponsored by DHS). General Electric modeled specific impact scenarios and produced damage predictions using a MANPADS missile model developed and supplied by RHAMM Technologies (Figure 4). Critical to the test is NAWC's proven ability to precisely control the missile's shotline, impact velocity, hit-point, and detonation delay. Doing so allows 1:1 correlation with modeled predictions of the test outcome which, in-turn, will be used to establish credibility of the engine-MANPADS modeling procedure.

Two tests will be performed to determine expected levels of damage and collateral effects. Shotline #1 on the operating CF6-50 will replicate a shotline used on a previous Phase I TF39 (C-5 aircraft) engine. This shotline involves the missile impacting the engine's tailcone and proceeding into the low-pressure turbine. The test allows a comparison of damage sustained by non-operating (TF39) and operating (CF6-50) engines. Shotline #2 on the CF6-50 involves what is perceived to be a more aggressive impact location into the high-pressure compressor. Operating engine parameters will be monitored and recorded before, during, and after the test event. These include engine speed parameters, temperature parameters, vibrations, and fuel flow rates. Strains will be recorded along key load-paths to assess missile-generated loads that get transferred through the pylon and potentially into the aircraft. Blast pressures within the engine core will also be recorded. High-speed video of the impact event will verify correct missile placement and function and will assist with post-test quantification of damage for 1:1 correlation with pretest predictions.

Upon conclusion of each test, thrust degradation characteristics and end damage states on the engine and the surrounding witness plates will be assessed, correlated with damage predictions, and shared with NASA for an evaluation (through flight simulation) of aircraft controllability, continued flight, and capability for performing a safe landing. While data generated by this program are specific to the engines and hardware involved, the estimated aerodynamic and systems effects of the damage will be modeled in a generic sense, representative of the effects on a typical large transport aircraft. Damage modeling will be implemented on NASA's Generic Transport Model (GTM) real-time piloted flight simulation. This full-scale simulation contains a high-aerodynamic-fidelity large-aircraft research simulation model (one of the highest in existence), and represents a large (200-passenger) twin-engine commercial transport configuration. This simulation is actively used for vehicle dynamics modeling and loss-of-control research under the NASA Aviation Safety Program. The safety-of-flight evaluation, which will consider several altitude, speed, and weight conditions, will also include an assessment of the damage-induced flight dynamics on similar aircraft configurations, both smaller and larger than the GTM.

The combined model-test-model engine-MANPADS effort represents a cost effective and low-risk method of determining the likely outcome of a MANPADS incident. The approach involves test and evaluation, coupled with modeling and simulation, to determine the effects of MANPADS hits on large modern engines. Results will also be applied to assess the validation of an engine-MANPADS modeling procedure for the purpose of damage prediction. The overall effort will complete a first-look at MANPADS damage effects on operating engines and the outcome on aircraft safety-of-flight. Such information will prove valuable to decision makers charged with operational risk assessments and development of counter-MANPADS technologies. ■

Combining Safety and Survivability for Future Spacefaring

By Robert E. Ball

As we move to the next generation of manned spacecraft, new initiatives would benefit from combining the survivability concepts of military aircraft design with the safety discipline of the spaceflight community.

Human spaceflight is a risky business. Spacecraft undergo very large acceleration forces during launch, travel through the atmosphere at great speeds, and, in the harsh environment of space, either connect with the international space station, remain in low Earth orbit trying to avoid orbital debris and meteors, or continue farther into outer space. Then, after what could be weeks or months, crew and passengers return to Earth, again traveling at very high speeds and under very high deceleration loads.

As difficult as this process is, it has been completed many times, thanks to the efforts of the NASA/industry human spaceflight community. One spacecraft, the space shuttle, has been launched 133 times since 1981. Unfortunately, two shuttles and their crews have been lost, Challenger during launch in 1986 and Columbia during reentry in 2003. These tragedies have resulted in a 'loss of vehicle and crew' rate of 1.5 per 100 launches, which is approximately the same as the combat loss rate of the B-17 bomber in World War II. This very high loss rate must be reduced if human spaceflight is to grow.

Figure 1 Flak damage completely destroyed the nose section of this Boeing B-17G, A 398th Bomb Group aircraft flown by 1Lt. Lawrence M. Delancey over Cologne, Germany. *USAF photo*

Figure 2 During Operation Iraqi Freedom, A-10 maintenance members from the 392 Air Expeditionary Wing inspect their aircraft for any additional damage after it was hit by an Iraqi missile in the right engine. The A-10 made it back to the base safely. *USAF photo/Staff Sgt. Shane A. Cuomo.*

The Military Aircraft Model

One way to lower the loss rate of spacecraft is to adopt some of the design processes and technology used to increase the survivability of military aircraft in combat. An aircraft takes off toward the target, which may be defended by one or more weapons or threats. As it approaches, it may be detected by enemy air defense sensors, tracked, engaged, and hit and possibly killed by ballistic projectiles, warhead fragments, or high explosive blasts. A large number of US military aircraft have been downed or lost in this man-made hostile environment since the early 20th century. For example, approximately 5,000 US fixed- and rotary-wing aircraft were lost in combat during the Southeast Asia (SEA) conflict from 1964 to 1973, with an overall loss rate of approximately one per 1,000 sorties. That's a lot of aircraft.

As a result of those losses, a new aircraft design discipline called aircraft combat survivability (ACS) was developed, starting in the early 1970s. Fundamentals have been established for this discipline, including a viable, cost-effective technology for enhancing survivability and a methodology for

Figure 3 During STS-115, micrometeoroid orbital debris struck the shuttle Atlantis and left a 0.108-in. ding in its right-hand payload bay door radiator. *Credit: NASA.*

assessing it. Live-fire testing for survivability is congressionally mandated, top-level survivability design guidance is prescribed, and quantified survivability requirements are now routinely specified by the Department of Defense.

The goal is the early identification and successful incorporation of those specific survivability enhancement features that increase the combat cost-effectiveness of the aircraft as a weapon system. In situations where the damage would lead to an aircraft kill, those survivability enhancement features should enable a gradual degradation of system capabilities, giving the crew a chance to eject over friendly territory.

As a consequence of this emphasis on increasing survivability, the number of US military aircraft lost in combat since the SEA conflict has dropped dramatically, and loss rates have been significantly lowered.

Although manned spacecraft are not currently threatened by weapons in space, this relatively new discipline could contribute to the needed improvement in the naturally hostile space environment.

Aircraft Survivability *vs.* Spacecraft Safety

Aircraft combat survivability is applicable to flight in a man-made hostile environment, but survivability can be more broadly applicable to flying in any hostile environment, including severe turbulence, lightning, birds, or crashes. Aircraft survive either by avoiding being hit by a damage mechanism—known as susceptibility reduction—or by withstanding any hit that does occur—vulnerability reduction. Stealth and electronic countermeasures reduce susceptibility because they make it less likely an aircraft will be hit; fuel system fire and explosion protection and redundant and separated flight control components reduce vulnerability because they make it less likely the aircraft will be killed given a hit.

The spaceflight community has a similar discipline devoted to safe travel. It is part of a package of disciplines known as safety, reliability, and mission assurance, or just safety and mission assurance. One of the major activities within NASA's Office of Safety and Mission Assurance is "improving methodologies for risk identification and assessment, and providing recommendations for risk mitigation and acceptance."

Risks are associated with hazards or conditions that can cause injury to a spacecraft's occupants or damage to the vehicle. For example, a piece of foam insulation could break away from the surface of a spacecraft and impact a critical portion of the craft's thermally protected exterior, a phenomenon known in combat survivability as cascading damage. The impact damage could cause a loss of the spacecraft upon reentry. If the hazard occurs, and people are injured or killed and the vehicle damaged or lost, as happened to Columbia, the result is known as a mishap.

Any potential hazard can pose a threat to the safety or mission capability of a spacecraft. In any safety program, risks or hazards are identified and then assessed, first by determining the severity of the subsequent mishap, possibly using a failure mode and effects analysis (FMEA), and then by estimating the probability the mishap will occur.

Risks, hazards, or mishaps deemed unacceptable because of their combination of severity and probability of occurrence must be avoided, mitigated, or, as a last resort, accepted if no satisfactory avoidance or mitigation technique can be found. Avoidance and mitigation techniques include eliminating the hazards through design selection, incorporating safety devices, providing warning systems, and developing procedures and training.

Comparing the two disciplines, safety is achieved by avoiding hazards, survivability by avoiding hits and thus reducing the likelihood a hazard or hit will occur. Safety is also achieved by mitigating hazards, survivability by withstanding hits, reducing the severity of the subsequent mishap or damage.

One difference between the two disciplines is the operational environment. The threats to the survival of a military aircraft are external and man-made. The current threats to the safety of a spacecraft are not man-made (except for orbital debris) and are both external (micrometeorites, orbital debris, radiation) and internal (such as mechanical or electrical breakdown).

When considering external threats, the survivability fundamentals can be applied to spacecraft as well as aircraft:

Figure 4 The loss of the shuttle Columbia and its crew of seven was a stark reminder that human spaceflight, though now viewed as routine, is still a high-risk undertaking.

Figure 5 Among the larger pieces of debris recovered from the crash of Columbia was its nose gear, shown here with its tires still intact.

avoid being hit by the damage mechanisms, if possible, and withstand any hits that do occur. (One could consider the external threat to spacecraft as a threat to its survival rather than a safety issue.)

When considering internal threats, the safety discipline relies on the traditional approach of hazard avoidance and mitigation. The survivability discipline, although developed for external threats, can also be used for internal threats if the definition of a hostile environment is expanded to include them. A leak, a fire, or a burst pressure vessel on board a spacecraft creates an internal hostile environment that must be withstood if the spacecraft is to survive. (Again, one could consider the internal threats as threats to the survival of the spacecraft rather than a safety issue.)

The difference in the nature of the threats to survival in combat and to safety in spaceflight influences how they are dealt with by the two disciplines. For example, the primary emphasis in system safety is the avoidance of hazards, particularly by preventing component failures through improvements in reliability. Similarly, the primary emphasis in survivability is to reduce the likelihood a hit occurs. Preventing a hit on a component is conceptually the same as preventing its failure—the component continues to function as needed.

The difference between the two disciplines shows up in safety's mitigation of hazards versus survivability's withstanding hits. In safety, if a pump fails, an adjacent back-up pump can be used. The severity of the mishap associated with the hazard occurrence is mitigated by the use of redundant pumps, and the resultant two-pump design is failure tolerant.

This is not the situation in survivability. When an aircraft is hit, damage can cascade. This cascading damage must be withstood if the aircraft is to survive. If a pump is hit and killed, an adjacent back-up pump could also be killed by the same hit or by cascading damage from the hit pump, and the functions provided by both are lost. Survivability requires redundancy with separation. As a consequence of this difference between safety's component failures and survivability's component damage, the combat survivability discipline conducts a damage mode and effects analysis (DMEA) after the FMEA when identifying the consequences of a hit.

The DMEA can also be used to analyze the survivability of a spacecraft design. In this situation, although the components are not hit by a damage mechanism, more energetic component failures are assumed, such as a liquid oxygen tank that bursts. This particular damage mode occurred on Apollo 13 when one of the two O2 tanks in the service module burst. Cascading damage caused a loss of the adjacent O2 tank and a subsequent loss of electrical power and air in the command module. In a more survivable design, the two tanks would have been separated so that a rupture of one tank would not cause the loss of both.

In short, the safety discipline focuses on hazard elimination and mitigation, whereas the survivability discipline focuses on avoiding hits and withstanding the subsequent damage when hits do occur. Safety is an *a priori* condition where hazards are avoided or mitigated during design; survival is a beneficial outcome of an undesired event. When safety fails, survivability is there to save the vehicle.

Combining Safety and Survivability

Because the fundamentals of the aircraft combat survivability discipline have direct applicability to the design of spacecraft, a merger or combination of both could be beneficial for future human spaceflight. The merger could take the form of a combined discipline known as safety and survivability, or a separate discipline could be developed known as spacecraft survivability.

If a combined discipline is chosen, NASA Procedural Requirements 8705.2B, Human-Rating Requirements for Space Systems, should be expanded to include the fundamentals of survivability enhancement developed for military aircraft. ("The human factor," page 3, and "Human rating for future spaceflight, A Roundtable Discussion," page 26, July-August, examine the ramifications of rating systems for human spaceflight.) If a separate spacecraft survivability discipline is chosen, a new process and requirements document should be developed.

This proposed combination has already begun for internal threats to the Orion crew exploration vehicle, originally part

Figure 6 An entire panel of the Apollo 13 service module was blown away by the apparent explosion of oxygen tank number two, located in sector 4 of the SM. Two of the three fuel cells are visible just forward of the heavily damaged area.

of NASA's Constellation program. Michael Saemisch, former safety and mission assurance manager for Project Orion on the Lockheed Martin contract, and Meghan Buchanan, lead engineer for the company's spacecraft survivability innovation for Orion, in collaboration with the Naval Postgraduate School Center for Survivability and Lethality, are developing a spacecraft survivability program based upon the fundamentals of the ACS discipline. Several design changes to Orion were made using this new approach. In June, the NASA/Lockheed Martin Orion team completed the Phase 1 Safety Review, making Orion the only spacecraft in development that meets all of NASA's human-rating criteria for missions beyond low Earth orbit.

Now is an opportune time to formalize the merger. NASA's Commercial Crew Development Program is currently working on a standardized integrated safety and design analysis process for the NASA commercial crew initiative that will be used for risk assessment during design, development, and demonstration of vehicles for human spaceflight. This work will focus on the integrated analysis process instead of prescriptive failure tolerance requirements to generate a safety-optimized solution. The DMEA and other design and analysis processes developed for enhancing the survivability of military aircraft should be incorporated into this new analysis, to ensure safer and more survivable spacecraft.

Recommendations

As the shuttle era draws to an end, new commercial initiatives are under way for human spaceflight. They can all benefit from the following recommendations, drawn from experience during the development of the aircraft combat survivability discipline:

- Safety and survivability should be merged or combined to form a new discipline for space systems, leading to improvements in both the safety and the survivability of human spaceflight in all environments. They should be essential elements, just as they are in military aircraft. This does not mean there will be no more losses—as long as there are flights, there will be losses. It does mean that any mishap will not be the result of a lack of foresight, insight, or oversight.
- Safety and survivability should be considered from the inception of any program, whether for military aircraft or a human-rated space vehicle. Any changes that have to be made well into the program because of postponed or neglected safety and survivability concerns will most likely be very costly in weight and dollars and may result in cancellation of the program, or even loss of life.

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Excellence in Survivability—William Keithley

by Eric Edwards

The Joint Aircraft Survivability Program (JASP) is pleased to posthumously recognize Mr. William Keithley for Excellence in Survivability. Keithley, who passed away on 16 November 2010, was an aircraft vulnerability tester and analyst for more than four decades. He was known as a practical, nuts-and-bolts expert on both foreign and domestic air systems, especially turbine engines and rotorcraft drive trains. The results of his efforts can be seen in virtually every Army combat helicopter (and many derivatives) flying today.

Mr. Stephen Polyak, a long-time friend and coworker at the US Army Ballistic Research Laboratory (BRL) (now the Army Research Laboratory [ARL]), said that the 63-year-old Maryland native will be remembered particularly for his innovation, resourcefulness, and adaptability in testing. “Bill knew more about the technical workings of all things mechanical, automotive, and aviation than anyone I have ever met,” Polyak noted, “The bottom line is that he made a difference in helping to reduce aircraft vulnerability and save lives.”

Dr. James Walbert, one of Bill’s former supervisors at ARL, agreed. “Bill was a man with an encyclopedic knowledge of aircraft survivability and testing techniques and procedures. And he always wanted to be sure that things were done correctly and reported properly. Bill was meticulous in his approach to testing and evaluation.”

Bill grew up in Edgewood, MD, where his father was a dairy farmer and his mother was a seamstress. From an early age, he was surrounded by many different kinds of engines and machinery. This practical, hands-on background prepared him well for his eventual life’s work with mechanical systems (as well as for many long-time hobbies outside of work, including vintage cars, go-kart racing, and tractor pulls).

Bill’s career in aviation began when he enlisted in the US Air Force in 1966. Here he served as an aircraft mechanic, crew chief for the 421st Fighter Squadron, and then assistant flight chief for the 366th Fighter Wing in Da Nang, Vietnam. His responsibilities in these positions included weapons uploading and overall fighter maintenance, as well as maintenance debriefs of pilots after combat missions. During his time in Southeast Asia, Bill was awarded the Purple Heart after he was injured in a mortar attack. His other Air Force awards included the Air Force Commendation Medal, the Bronze Star, and the Presidential Unit Citation. He left the Air Force in 1969 after achieving the rank of staff sergeant.

In 1970, Bill joined Ross Aviation and worked as an FAA helicopter maintenance mechanic and inspector. His responsibilities included flight readiness, inspection, and post-flight discrepancies. He also served as an in-flight crew chief, flying on tests and VIP visits. Most importantly, it was during this time at Ross that Bill became acquainted with Aberdeen Proving Ground and the Phillips Army Airfield. Little did he know that this remote test facility would be his home away from home for the next 40 years (as well as his job site for three different employers).

In 1976, Bill began his 27 years of civilian service at BRL/ARL, serving first as a lead aircraft mechanic, then senior test director, and then range manager. As a mechanic, Bill performed target quality control, collected and certified data for FAA approval, and was responsible for numerous foreign fixed- and rotary-wing targets (such as the Russian MiG-23/27 and the Mi-24). In addition, he participated in a high-visibility laser development program, where he helped test laser damage against optical aircraft materials. The result of this work contributed to today’s modern airborne laser systems.

As a BRL test director, Bill used his knowledge of a wide range of foreign and domestic ammunition and rocket and missile warheads to plan and conduct numerous ballistic tests against various targets. Notable tests in which he participated included the GAU 8 and the 30-mm Bushmaster gun development programs.

As range manager, Bill was responsible for the operation of ARL’s Rotorcraft Survivability Assessment Facility during one of the facility’s most extensive expansion and modernization periods. Simultaneously, he helped to orchestrate several important test programs, including the complex testing of several foreign systems. Bill developed multiple test rigs and setups to test engines, gearboxes, drive shafts, and other systems and subsystems. In addition, his execution of more than 30 Live Fire shots on the T-700 engine helped establish the most extensive database of test information for shots against running turbine engines. He was also

Figure 1 Bill Keithley Next to One of the F-4's He Maintained in Vietnam, Circa 1968.

instrumental in the developmental testing of main blade hit under full-power operation, and he helped develop and use an innovative remote control system to test the Mi-24 Hind, UH-60, and AH-64 Longbow rotorcraft. Bill also sat on the source selection boards for the Utility Tactical Transport Aircraft System, the Advanced Attack Helicopter, and the Kiowa Warrior. And he evaluated several ground systems, such as the SGT YORK XM 1 Leopard tank and the General Motors version of the XM1.

Not surprisingly, Bill's extensive experience and longevity in the business also made him an invaluable resource for younger test engineers. "When 'new' problems would arrive on the range," Polyak said, "Bill would often have the answer because he had 'been there and done that.' And it wasn't just his knowledge of aircraft systems; it was his application of that knowledge, directly and by advising and assisting others, that made many a test possible."

Mr. Dirck Ten Broeck, another long-time ARL colleague, agreed. "Bill's ability to explain even the most complicated of aircraft subsystems, often to the aid of newer analysts, was extraordinary."

Another key to Bill's successes during his time at BRL/ARL was undoubtedly his close working partnership with Mr. Walter Thompson (who was previously recognized as a Pioneer in Survivability in the Spring 2009 issue of *Aircraft Survivability*). For the most part, Walt supplied the ideas and analysis, and Bill supplied the testing and implementation. The Thompson-Keithley partnership worked particularly well in testing and analyzing foreign aircraft. "The two of them put in a lot of hard work figuring out foreign methods and techniques," Polyak said, "and without the benefit of technical manuals. They not only knew how these aircraft worked, but they also knew how to modify them and fix them when they stopped working."

After his retirement from Government service in 2003, Bill teamed up with Walt one more time as the two continued their aircraft survivability work for the SURVICE Engineering Company in Belcamp, MD. At SURVICE, Bill added yet another hat to his extensive collection, that of senior analyst. Mr. Rick Grote, the Chief of ARL's System Engineering and Experimentation Branch, recognized the potential value of having Bill's hands-on testing experience and broad practical aircraft knowledge directly accessible to all the analysts, and so he had Bill embedded on ARL's Aviation Analysis Team. And now looking back on Bill's performance, Grote considers this personnel decision one of the best he has ever made as a manager.

"The 'transformation' that Bill made from tester to analyst," Polyak said, "is not that common in this business, but he made the switch quite smoothly and was a big contributor to the modeling and simulation process for both fixed- and rotary-wing aircraft."

Bill analyzed US propulsion, rotor drives, and rotor blades, as well as foreign rotorcraft subsystems, such as flight control, electronics, fuel systems, hydraulics, and landing gear. In addition, he developed and reviewed failure modes and effects analyses (FMEA) and probabilities of component damage given a hit ($P_{CD|H}$) data sets, as well as correlations to target descriptions for MUVES inputs. The list of systems Bill supported during this time includes the UH-60M, MH-60M, AH/MH-6M, CH-47F, UH-60M Fly-by-Wire, Sky Warrior, Mi-8, Mi-24, Ka-50, and Mi-17. He was also a major contributor to the Joint Cargo Aircraft (JCA) for MUVES analysis. And he reviewed and approved inputs and MUVES outputs, including comparison of predictions and Live Fire shot data on the platform or surrogate targets, as well as geometric target descriptions of foreign platforms.

In the latter years of his life, Bill began to face numerous health problems (including a kidney transplant and two liver transplants), but he continued to work and to try to impact the field of aircraft vulnerability with a tenacity that amazed many of his colleagues.

"I always admired Bill's determination and drive," said Brian Smith, another former ARL coworker and team leader. "Whether it was chasing down an answer to a question or fighting health problems, Bill just never gave up."

Bill is survived by Tina, his wife of 44 years; as well as two children, Melissa and Bill Jr.; two grandchildren; and one great grandchild. ■

V_{50} versus V_0 Armor Measurements and Modeling

by Jim Rhoads

As defined in MIL-STD-662F, a material’s Ballistic Limit (or V_{50}) is *“The minimum velocity at which a particular projectile is expected to consistently, completely penetrate armor of given thickness and physical properties at a specified angle of obliquity. The ballistic limit is the maximum velocity at which a particular projectile is expected to consistently fail to penetrate armor of given thickness and physical properties at a specified angle of obliquity. Because of the expense of firing tests and the impossibility of controlling striking velocity precisely, plus the existence of a zone of mixed results in which a projectile may completely penetrate or only partially penetrate under apparently identical conditions, statistical approaches are necessary, based upon limited firings. Certain approaches lead to approximation of the V_{50} Point, that is, the velocity at which complete penetration and incomplete penetration are equally likely to occur.”* Also from MIL-STD-662F, the term V_{50} ballistic limit is *“In general, the velocity at which the probability of penetration of an armor material is 50%.”* Given these definitions, a V_0 is the velocity at which the probability of penetration is 0% and the threat is stopped 100% of the time.

Many new acquisition programs’ procurement specifications include Key Performance Parameters (KPPs) for crew protection or specifically require armor in key locations on the platform. In most cases, the armor specification is for a V_{50} performance value. In addition, the penetration equations used by the widely well-known models (COVART, AJEM, MUVES models) used to estimate the vulnerability of a system employ ballistic penetration equations that assume V_{50}=V_0 for all penetrations, i.e. the model assumes no penetration for threat velocities less than V_{50}. Therefore it is important to understand the differences between a V_{50} and V_0.

Figure 1 illustrates a sample ballistic probability curve showing two separate techniques for estimating a V_{50} and one technique for estimating a V_0. The first V_{50} technique, commonly known as the 3 up 3 down, averages the three slowest complete penetration velocities (blue diamond symbols with a 1.0 probability of penetration) with the three fastest partial penetration velocities (blue diamond symbols with a 0.0 probability of penetration). Averaging these six points produces a V_{50}=1,663 feet/second. A second technique uses all the data generated during a ballistic test series and applies a Least Squares fit to the data. The resulting curve and where it intercepts the 0.5 probability of penetration represents the V_{50}, or in this example V_{50}=1,668 feet/second. The light grey shaded area in Figure 1 shows the overlap between complete penetrations and partial penetrations known as the zone of mixed results. The zone is quite narrow if the armor displays homogeneous characteristics and test techniques are tightly controlled. The zone is quite broad if the material design is not consistent (poor process controls) or uses varying material properties (composite/ceramic design), or if the test techniques are not tightly controlled. Ballistic Technology of Lightweight Armor (U) (F. Mascianica, MTL Technical Report AMMRC-TR 81-20, Watertown, MA, May 1981) provides a thorough explanation of a zone of mixed results along with numerous examples. Mascianica proposed testing for a V_{50} and using the three velocity standard

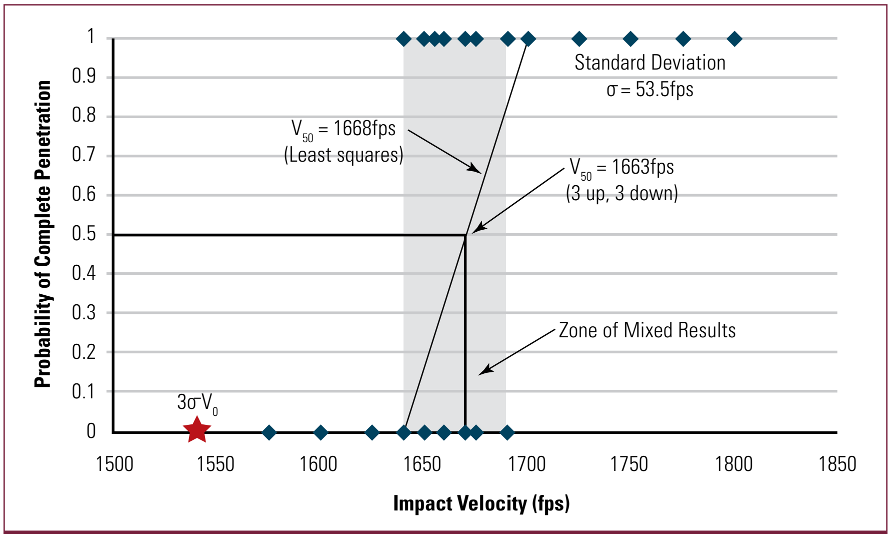

Figure 1 Sample Ballistic Penetration Curve

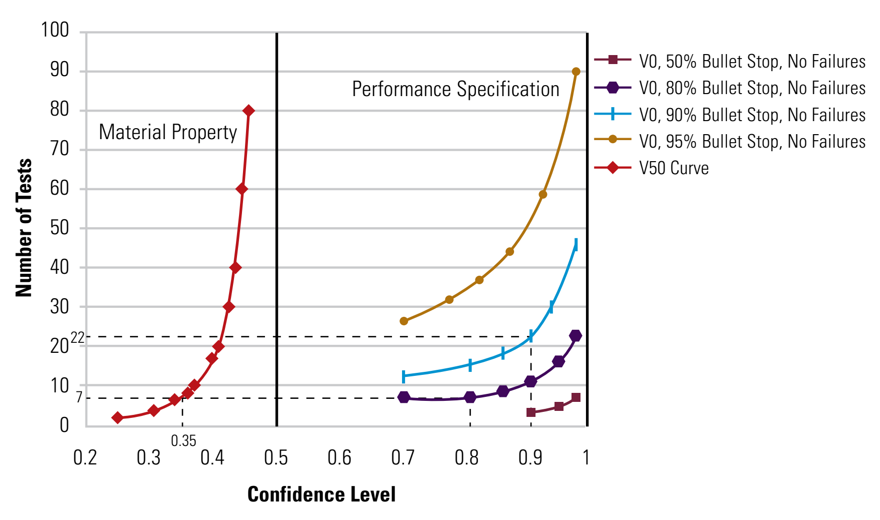

Figure 2 Confidence Level Based on n-tests for Various Armor Performance Levels

deviations lower than the V_{50} to establish the V_0. We were not able to find test data that represent this idea, but Figure 1 shows a representation of this concept.

Limitations of Current Testing and Modeling

Because of the way vulnerability analysis tools model penetration, choosing how to model an armor panel in a system level assessment is extremely important. As currently implemented, the penetration equations within the vulnerability models assume that once a threat's impact velocity degrades below the V_{50} of the impacted panel, the threat stops. Consequently the models do not track a threat's path behind a plate once the impact velocity falls below the V_{50}. In essence, the models consider a projectile not to have penetrated for velocities less than V_{50}, *i.e.* the $V_{50}=V_0$. This assumption will cause problems for any vulnerability assessment looking at armor application with a design requirement for a ballistic V_{50}. To illustrate this point, we use a simple example of a flight control computer that is singly vulnerable on a new aircraft design. Despite their best efforts, the vulnerability analysts were unable to separate or require redundant systems, but they were able to obtain a weight budget for armor. The analysts select a vendor to design an armor to defeat a 7.62mmx39 Armor Piercing Incendiary (API) projectile traveling at 2,000 feet per second. In writing their specification, the analysts define the armor's performance as a V_{50}. After a successful test and development program, the analysts incorporate the armor into the vulnerability assessment (modeled as a piece of steel with the equivalent V_{50} of the armor) and accept credit for 100% protection of the flight control computer. However, this is incorrect. Since the armor's V_{50} is 2,000 feet per second, that simply means the armor will defeat the projectile 50% of the time at that velocity. In other words, the armor does not provide 100% protection from perforation, but less than 50% with unknown damage consequences for the remaining percent of the time. In this example, the analyst should use the three sigma deviation to establish a V_0 or specify the armor design as a V_0.

Proposed V_0 Test Method

In order to avoid this modeling error, the analysts could have required the armor to perform to a V_0 standard. That way, the modeling and test results would have been equivalent. But how can you design and test for 100% protection all the time without doing thousands and thousands of tests? Statistical methods allow for the design of a system by assigning confidence values to the results of the test, allowing the decision makers to determine if they accept the risk or not. Figure 2 shows some different examples of test performance curves and their relationships to confidence levels and the numbers of tests required to reach those levels. These curves are based on a binomial distribution and assume no failures (except the V_{50} curve) during the test series (consecutive successes). All of the curves except one represent a V_0 curve with a probability of stopping a bullet. As the number of test points for each curve increases the confidence that the threat is stopped increases as well. The V_{50} curve in Figure 2 shows that the confidence in the design solution reaches 50% as the number of tests increase (this assumes the system always fails half of the time). For the V_0 curves, the confidence level approaches 100% as the number of tests increases. By selecting a desired number of test events, one can obtain different confidence values in the armor performance. For example, if the test manager performs only seven tests, the data in Figure 2 show a V_{50} with a confidence of 0.35 (assuming 50% of the tests fail), or at least a V_{20} performance with 80% confidence (another way to say this is a V_0 with the projectile being stopped 80% of the time with an 80% confidence).

Using this approach, a design team could easily test and develop a V_0 system without significantly increasing the cost of the design. Potentially, this could involve use of a design of experiments to test various thicknesses, impact velocities, and obliquity angles that would increase the confidence of the final armor design so when the final V_0 testing is performed, there is a high confidence the system will pass every time at the given threat velocity. However, one must remember that should a failure occur during the V_0 testing, the confidence level dramatically decreases, or the design changes. The benefit of the V_0 approach is that the armor is designed to stop the bullet 100% of the time with some confidence. In the earlier example with the flight control computer, if the armor was designed to a V_0 with 90% confidence the armor will stop the bullet 90% of the time, 22 consecutive tests are required to pass (see Figure 2). In addition, the vulnerability analyst would reduce the vulnerable area of that component by 90%, not 50% as with the V_{50} example. This technique produces a more realistic answer and should support data from combat and other Live Fire Test events.

As noted on Figure 2, the V_{50} value is the equivalent of a material property, much like yield strength. Once the armor design is set, the V_{50} allows for comparison to other materials/compositions. No matter the armor design, the V_{50} is still a valid material property to measure and record, and at a minimum could be used for Lot

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Aircraft Survivability for Counter-insurgencies

by Nicholas Hardman

Current US military aircraft were designed and acquired based on a paradigm of war very different than those currently being waged in Afghanistan and Iraq. So how have our aircraft fared in counter-insurgency (COIN) operations, and what revisions to survivability requirements are implied by the results? This paper seeks to make survivability engineers informed consumers of combat damage assessment data, and contributes observations from Afghanistan for use in survivability decision-making.

Combat Damage Assessments

As a Joint Combat Assessment Team (JCAT) member currently deployed to Northern Afghanistan, I am part of the survivability community's real-world data source. JCAT, referred to as "CSI in the sky," performs forensic analysis on US downed or damaged aircraft in order to determine the enemy's capabilities and the performance of aircraft survivability systems. [1] JCAT is composed of members from across the Department of Defense (DoD). It is sponsored by the Joint Aircraft Survivability Program Office and includes the Navy's Combat Aircraft Survivability and Threat Lethality (CASTL) team and the Army's Aircraft Shoot-Down Assessment Team (ASDAT). Unfortunately, we have had a lot of business. That means investigating charred aircraft remains and interviewing our nation's newest Purple Heart recipients.

JCAT members investigate, identify, and catalog aircraft combat damage with a disparate audience in mind. Our most immediate customers are the operational commanders. They want real-time threat analysis for use in mission planning. At the same time, intelligence organizations want to know compiled trends and any identified "shifts in battlefield atmospherics". More distant from the fight, but more significant to affect long term change, are the survivability engineers.

Figure 1 U.S. Army OH-58 Kiowa Warrior Helicopter

Combat is the ultimate operational test and evaluation (OT&E) program. Hundreds of aircraft have been hit by hostile fire in both Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF). "JCAT'ers are continually mindful of ways to reduce the factors of un-survivability; *i.e.*, susceptibility (inability of aircraft to avoid being hit) and vulnerability (inability of an aircraft to withstand the hit). Survivability engineers are able to access those analyses and the raw data behind them to aid in sound acquisition decision-making. For instance, JCAT-compiled data has been used to validate aircraft survivability simulations such as the Computation of Vulnerable Area Tool (COVART). [2]

The forward presence of JCAT assures data integrity and completeness. That is, we are embedded within, but operationally autonomous of, our host units. I was recently called in to examine a helicopter that Military Intelligence (MI) reported being hit by "something big." In my assessment, I could not rectify the aircraft damage with the implicated threat system. The organization had already processed this one as a hit, but a mantra of JCAT training was, "Never adjust reality to fit conclusions." Upon closer examination, I found that the damage could be fully explained by liberated fasteners that had impacted the tail rotor and were then batted into the empennage. The MI report of a stealth enemy anti-aircraft gun was rescinded, and the combat damage database was able to maintain fidelity.

For catastrophic events, the forward team is often augmented by ASDAT members from Ft Rucker, AL. These are experienced pilots equipped for major combat damage events. [3] Recently, one of our aircraft went down in a hostile area. Media reports proposed that the crash was caused by a wire strike. The brigade tactical operations warrant officer (TACOPS) and I were inserted with a foreign commando unit to inspect the wreckage. I processed the collected evidence through an in-theatre forensics laboratory. While the assessment was still ongoing, Army leadership requested a safety team be brought into theatre to pursue the wire strike theory. A qualified ASDAT member joined the team, and I briefed them of my work to date. Once their investigation concluded that the facts implicated hostile fire, the ASDAT representative and I continued the assessment, ultimately identifying both the probable threat weapon and a series of recommendations to mitigate future risk.

Combat Damage Results from OEF

So, from a survivability perspective, how are we doing in the present conflicts? Well, the specifics of JCAT assessments are classified, but, for the purposes of a qualitative discussion, the following figures summarize data from the period that JCAT has had a resident presence in the Afghan theater (2009 to present).

As shown in Figure 2, rotary wing (RW) transport aircraft incurred the most incidents of damage due to hostile fire. Included in this category are Army CH-47s and both Marine CH-53s and (for taxonomical purposes only) the V-22. The remaining incidents are almost evenly split among the other helicopter categories. That is, RW medical evacuation (MEDEVAC, UH-60As and Air Force HH-60s), RW Attack (Army AH-64s and Marine AH-1s), RW Observation (Army OH-58s), and RW Utility (UH-60s and UH-1s). Only a very small percentage of the incidents involved fixed wing aircraft with most of those involving C-130 variants that perform airdrop re-supplies and operations at austere airfields.

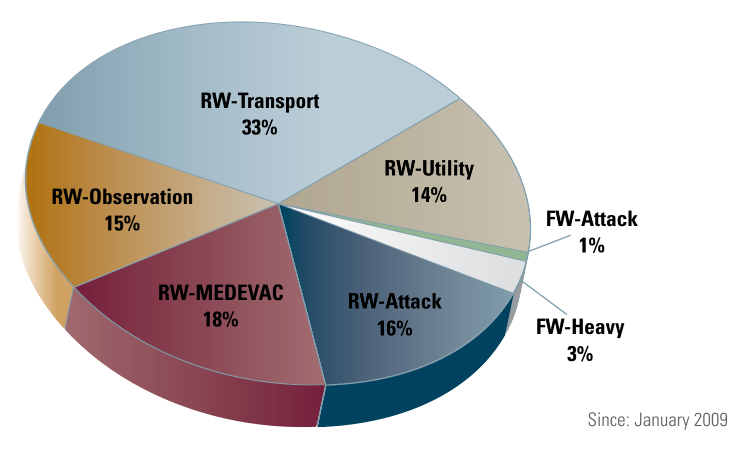

Figure 2 OEF Aircraft Combat Damage by Aircraft Type

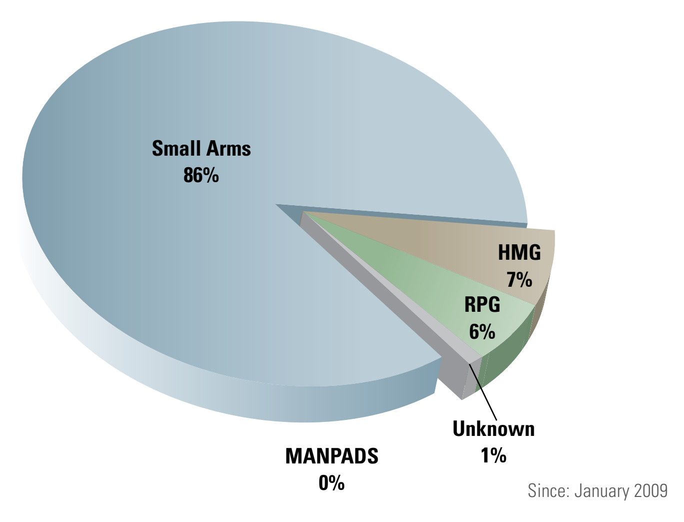

Figure 3 OEF Aircraft Combat Damage by Threat Type

Besides producing and collecting this data, JCAT studies it for aircraft loss rates, hit rates (*i.e.*, hits per unit of flight hours or per mission) and hit success rate (*i.e.*, hits per reported attempts). These rates were found to vary widely for the aircraft listed. Additional data is available for those with proper clearance, but for a frame of reference, current loss rates are less than one tenth of those from the Vietnam era. [4]

Figure 3 summarizes what weapons the enemy has been able to successfully employ against our aircraft. As it can be seen, the overwhelming majority of combat damage in Afghanistan has been caused by small-arms fire. This category includes all hand-carried rifles such as the AK-47. The heavy machine gun (HMG) category includes all larger caliber, typically mounted, weapons such as the 12.7 mm DSHk and PKM. Also included is the 14.5 mm ZPU family of weapons. The final category with any significant percentage of hits is the rocket propelled grenade (RPG) which fires an unguided projectile that detonates on contact or by a self-destruct timing fuse.

Observations

That is what war with an insurgent force looks like. Aircraft are a very useful asset in COIN, but without clear lines of battle, every flight is a combat sortie. While the enemy pays no heed to laws of armed conflict, we operate under very restrictive rules of engagement (ROE). Additionally, the current battles are being waged in hot, rugged, high terrain where rotary wing aircraft are power-limited and surface to air attacks are easy to conceal. A few observations:

Survivability efforts are cost-justified

As Ball discusses in [5], the discipline of aircraft survivability developed several decades ago. We are seeing the fruits of that revolution in the number of aircraft that are engaged by the enemy, yet return to base. Besides the benefit to human welfare and operational planning, it is a life-cycle cost win; every aircraft that can be repaired is a return on investment for the discipline.

The US has developed highly sophisticated countermeasures to protect our aircraft against guided missiles, and some would use the preceding data to challenge such expense. One must keep in mind that

Figure 4 Rocket Propelled Grenades Rounds

the data represents successful attacks. The enemy has had the will, the opportunity, and the means to attack with guided weapons. Their lack of successful employment should not be a cause for complacency, though it has been very discouraging for the enemy.

Susceptibility: Sometimes, you are less with less

Susceptibility is a systems parameter; it must be analyzed with systems thinking. We have confronted numerous modern threats by going high tech; and achieved notable success, such as just mentioned. However, the value of any new box must be assessed with and for each entire weapon system that it is to protect. In an example from the fixed-wing world, many transport aircraft are getting new infrared countermeasure packages. Though OT&E has affirmed its effectiveness, the aircraft modification comes with a weight and drag penalty. In the conditions of our current conflicts, that means a reduction in operational capability and maneuverability for some C-130 variants. Deployed aircrew members are opposed to sacrifices in those areas and question the true reduction in system susceptibility, given the sacrifice.

As a counter example to affirm my support for technology insertion, the brave pilots that fly surveillance flights do so in the slowest, cheapest, and least armored manned aircraft in the Army, yet provide a critical operational capability. They must get down in close to make positive identification of enemy forces, thus satisfying onerous ROE… but at a price! They need some survivability engineering attention, but their greatest survivability gain may lie outside the traditionally-identified fixes. In effect, those aircrew are doing COIN with a sensor suite designed for conventional warfare. Identifying insurgents in village streets requires a much more sophisticated set of eyes than detecting columns of tanks in open grassland. Modifications have begun to add more armor, but the bird is already weight-limited. Maybe we don't have to make them get so close. Modern sensors could actually result in a net weight reduction. Can we reduce susceptibility by enabling them to perform the mission with the same effectiveness but with greater standoff?

Vulnerability: Go smarter, not harder

With weight so critical, adding armor to aircraft always involves sacrifice. How often would it be better to design for "taking a punch" rather than blocking it? That requires designing in resilience, *i.e.*, fault-tolerant subsystems and the ability to prevent cascading failures. For example, several recent hostile fire incidents have resulted in helicopter engine failures. Generally this does not preclude a safe return to base, but some helicopters in certain flight regimes cannot keep their electrical generators on line during reduced engine operation. If electrical power is lost, otherwise-functional pressure valves will not remain closed. If the pressure valves open, the reduction in power from the working engine is insufficient. Notice that, in such scenarios, the ultimate cause of unsustainable flight was not directly caused by the enemy.

Another use of battlefield data can be that you learn where you need armor, but maybe not as much. Sun Tsu said, "If you try to defend everywhere, you defend nowhere," or words to that effect. [6] Combat damage investigations on Cobra and Apache aircraft have revealed that the standard for transparent armor, commonly referred to as "bulletproof glass" can be reduced for aircraft. The standard was adopted from those for ground vehicles and we have found that moving aircraft just don't get hit repeatedly in exactly the same place. What should be the standard? That is the subject of active research by a member of ASDAT. Regardless of the specific ratings, I can attest to the welcome reception that the potential weight savings will receive in theater.

Summary

In sum, the data confirms that aircraft survivability has improved, but we still have a lot of aircraft getting hit and pilots becoming casualties. A decade of irregular warfare has shown us that there is no single static solution. Though they have not made previous efforts moot, the current conflicts have created more challenges to aircraft susceptibility and vulnerability, thus requiring survivability engineers to remain in continuous review and improvement. ■

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Aircraft Combat Reporting – Forward Deployed Success

by David Mullins

During Operation Enduring Freedom and Operation Iraqi Freedom (OEF/OIF) a joint group of Reserve Air Force, Marine Corps, Navy and Army personnel were deployed to Iraq to begin the process of data gathering on aircraft damaged in combat. This was the first full time deployment for the Joint Combat Assessment Team (JCAT). Overall, the mission to collect battle damage data began during the Vietnam Conflict. Since its inception in December of 1984, the Survivability Information Analysis Center's (SURVIAC) mission has included the collection of combat damage data, and since that time has accumulated over 30,000 incident reports spanning the past 50 years of conflict. These reports have been used over the years as a source of Live Fire Test and Modeling and Simulation data validation, as well as a source of feedback to the Acquisition and Engineering Communities and the Aircraft Survivability Community.

During the most recent conflicts, as more aircraft were hit, crews lost, and new threats appeared, it became clear that the data being collected needed a centralized location for storage and dissemination. JCAT came to SURVIAC with this requirement. Working with the Joint Aircraft Survivability Program Office (JASPO), the Combat Damage Incident Reporting System (CDIRS) was born. This database contains over 1500 high fidelity investigation reports, most containing high resolution images, incident video, crew interviews and mission narratives. CDIRS is used on a daily basis as a bridge between the forward deployed JCAT units and the aircraft survivability community in the United States. As incidents are reported, analysts are able to view quick-look (less than 24 hours since incident occurrence) reports and eventually, the full reports describing in depth, the damage to aircraft, crew, and current threat assessments.

CDIRS began as a simple data collection effort using an FTP site as a file repository for JCAT reports. As the number of reports and requestors grew, it became apparent that an FTP site would no longer suffice and it certainly was not capable of data manipulation and data massaging. A database was needed.

In 2005 the first version of CDIRS was complete but represented more of a proof of concept than production system. SURVIAC worked with various Services and Wright Patterson AFB communication offices to host the server on the SIPRNET and provide initial inputs for requirements for data points to collect. The initial database was available within months but was hampered by low bandwidth capability in theater. SURVIAC worked closely with JCAT during that year to provide solutions to the bandwidth issues in Iraq, but mailing a CD/DVD proved to be the most efficient way of getting large amounts of data out of theater.

Over the next two years, SURVIAC worked on several updates to this system, bringing requirements under control and managing the level of expectation for the granularity of data being collected. The reporting requirements started to become onerous to the personnel in theater and filling out a form with 80+ data points took far too long. An overhaul of the system was needed.

Starting in 2008, SURVIAC set out to build version 2.0 of the CDIRS database. The database was reexamined and greatly improved. With an eye toward simplification, the system was rebuilt from the ground up, providing multiple search capabilities. It also provided cleaner data entry forms and capability for future growth. Organizations throughout the Department of Defense (DoD) have been able to access CDIRS reports, providing vivid, real-time data for Research and Development efforts, survivability improvements and feedback for Original Equipment Manufacturers (OEM) and program offices. The reports have been used for a variety of programs including the Hostile Fire Detection System, the Common Missile Warning System, the Large Aircraft Vulnerability Study, the Study of Rotorcraft Survivability and the ongoing effort to bring down the risk of crew causalities among aircrews in damaged aircraft. ■

Dale Atkinson Receives Arthur Stein Award

by Lowell Tonnessen

On 7 June 2011, the Test and Evaluation (T&E) Division of the National Defense Industrial Association (NDIA) presented Mr. Dale Atkinson with the Arthur Stein Award for outstanding contributions in live fire test and evaluation (LFT&E). The award was given at the organization's LFT&E Conference at Eglin Air Force Base, FL.

On 7 June 2011, the Test and Evaluation (T&E) Division of the National Defense Industrial Association (NDIA) presented Mr. Dale Atkinson with the Arthur Stein Award for outstanding contributions in live fire test and evaluation (LFT&E). The award was given at the organization's LFT&E Conference at Eglin Air Force Base, FL.

In accepting the award, Mr. Atkinson said: "I knew Art Stein for many years and am very pleased to receive an award named after him. He was truly a gentleman, similar to Larry Eusanio, whom we also miss. I am impressed with how far we have come since we started this type of testing by working together. I am sure that we will continue to make progress under the LFT&E and JLF programs, which will help improve the survivability and effectiveness of our weapon systems. Our goal has been to help the warfighters and I think we are doing that rather well. Thank you all very much."

Before the award was presented, Dr. Lowell Tonnessen of the Institute for Defense Analyses provided attendees with some highlights of the career, accomplishments, and writings of the award's namesake. "At first glance," Dr. Tonnessen said, "it might seem odd to name the Live Fire Test and Evaluation award after a man who already was semi-retired when LFT&E was Congressionally mandated, and who passed away almost 16 years ago. But Arthur Stein was not a usual person. He led a distinguished career, he made major contributions to Live Fire Test and Evaluation, and he was loved. It is for all of these reasons that we continue to give the LFT&E award in his name." Previous recipients of the Stein Award include Dr. Tonnessen and Dr. Paul Deitz (1997), Mr. Walt Hollis (1999), Dr. Bob Ball (2000), Mr. Jim O'Bryon (2002), Dr. Ron Reese (2003), Mr. Larry Eusanio (2007), and Mr. Tracy Sheppard (2009).

The award was presented by Jim O'Bryon, chair of the NDIA T&E Division, who gave the following insights into the substantial achievements of Mr. Atkinson:

"Over a long career of almost 50 years, Mr. Atkinson was, in large part, responsible for the formation and establishment of institutions that have made major contributions to Live Fire Test and Evaluation, in particular, the Combat Data Information Center (predecessor of today's DoD Survivability/Vulnerability Information and Analysis Center (SURVIAC)), the Survivability and Lethality Division at the Naval Weapons Center, China Lake, and the Joint Technical Coordinating Group for Aircraft Survivability (JTCG/AS), now known as JASP.

"Dale Atkinson's career in aircraft survivability began in the early 1960s at the Flight Dynamics Laboratory, Wright–Patterson Air Force Base, OH, where he became Chief of the newly-established Survivability/Vulnerability Branch. During the Vietnam War, he was a key member of an Air Force field survey team to determine the causes of aircraft losses in Southeast Asia. Design changes resulting from this project were incorporated in the F-4 and F-105 to make these aircraft more survivable. At Wright-Patterson, he played a major role in developing survivability programs for the A-10 and F-15. He was instrumental in establishing the Aircraft Survivability Research Facility, which made possible more realistic live fire ballistic testing. During this time he was, in great measure, responsible for establishing the Combat Data Information Center, the predecessor of today's SURVIAC.

"In 1973, he moved to the Naval Weapons Center, China Lake, California, where he played a major role in establishing the Survivability and Lethality Division and was appointed Associate Division Head.

"In 1975, he was asked to come to Washington, DC, where he helped form the Combat Survivability Branch at the Naval Air Systems Command, later becoming Branch Head. During his 15-year tenure, he continued to work toward establishing survivability as a fundamental discipline in aircraft design. He served as the initial survivability project engineer for the F/A-18, an aircraft whose damage-tolerant design was proven during the 1991 Gulf War. As Branch Head, he was also responsible for supporting a number of other programs including the development of survivability features for the new V-22 Osprey tilt-rotor aircraft. He also served with great effectiveness as the Navy's Advanced Development Project Officer for aircraft survivability.

"Of special relevance to LFT&E was his critical role in establishing the JTCG/AS, which has grown into the Joint Aircraft Survivability Program Office and is today a major survivability resource for the military services, the Office of the Secretary of Defense (OSD), and industry. He served with great distinction as its Chairman from 1981 to 1987, during the fast-paced defense build-up of the Reagan years, and the earliest days of Live Fire Testing.

"His final assignment in government was as OSD Staff Specialist for Survivability and Battle Damage Repair. Since retiring from government service, he has remained active in the field of survivability, working with the JASP Office, the Institute for Defense Analyses, the Federal Aviation Administration, and other organizations. Survivability practitioners and senior executives continue to seek his counsel on matters concerning aircraft survivability and overall mission effectiveness. As Assistant Editor of the Aircraft Survivability journal, he has developed themes for each issue, identified authors who are subject matter experts and gifted writers, and overall has ensured the quality and readability of the journal.

"Throughout his career, he has selflessly advanced the cause of aircraft survivability in the military services, OSD and industry. Perhaps more than anyone, he has ensured that the aircraft survivability community is a true community. He is quick to give credit to others, and has ensured that colleagues receive recognition for their accomplishments. He has been a strong advocate for survivability education, and was an early supporter of Dr. Robert Ball's efforts to author a definitive aircraft survivability textbook, for which Dr. Ball received the Arthur Stein Award in the year 2000.

"As a result of Dale Atkinson's efforts and achievements, combat survivability today is recognized as a key military aircraft design discipline, viewed as essential to overall combat mission effectiveness. His many achievements clearly exemplify the level of superior performance represented by the Arthur Stein Award for Lifetime Achievement in Live Fire Test and Evaluation. As a final comment, I know that Art Stein knew Dale Atkinson well, worked with him, and respected him. Art Stein would be proud to know that Dale is receiving this award today. Congratulations, Dale Atkinson! You make us proud!!" ■

V_{50} versus V_0 Armor Measurements and Modeling

Continued from page 19

Acceptance testing. However, the V_0 tends to support performance specification requirements better than the V_{50}. For the many reasons already mentioned, the V_0 better supports the concept of what armor is intended to do: stop projectiles 100% of the time.

Conclusion

This paper presents differences between the V_{50} and V_0 with a specific focus on usage in vulnerability modeling. Vulnerability analysts with armor in their designs need to use the correct armor performance curves or risk misrepresentation of the component or system vulnerability. It is important to remember a V_{50} armor design means that 50% of the time the armor will not stop the threat. ■

Survivability Short Course

by Chris Adams and Mark Couch

The 2011 Joint Aircraft Survivability Program (JASP) Short Course was held 17–20 May at the Naval Postgraduate School (NPS) in Monterey, CA. 52 students attended the course, including military, civilian, and contract employees working for Department of Defense, industry, and academia. The lead instructors were Chris Adams, Director of the Center for Survivability and Lethality at the NPS, and Dr. Mark Couch, Research Staff Member at the Institute for Defense Analyses.

The course was designed to introduce students to the aircraft survivability discipline building on the pioneering work of Distinguished Professor Emeritus Robert Ball, who developed the first graduate-level course on aircraft combat survivability at NPS in the 1970s. The unique aspect about this course is that it includes both susceptibility and vulnerability while other courses may focus on only one area or part of one. Attendees received a copy of the textbook, *The Fundamentals of Aircraft Combat Survivability Analysis and Design*, 2nd Edition, and a notebook containing the lessons and presentations. Selected chapters from the "Threat Effects" video developed by JASP were shown to highlight current threats to aircraft and techniques used to reduce vulnerability to these threats. Additionally, presentations by experienced combat pilots in Iraq and Afghanistan were included to give the students the pilot's perspective.

In the keynote address on the first day, Dr. Ball gave a presentation on the history of the aircraft survivability discipline. The students thoroughly enjoyed learning about survivability from the author of the world's only textbook on the subject and listening to his recounting of how the discipline originated and why it is still needed today. He concluded his remarks by challenging students to tackle deficiencies in the survivability discipline and to continue learning about survivability in a constantly changing environment. Dr. Ball was available throughout the remainder of the course to sign copies of his text and answer students' questions.

Figure 1 Dr. Robert Ball Contemplates a Response to a Student's Question at the JASP Short Course

To kick off the second day, Mr. Rick Sayre, the Director of Live Fire Test and Evaluation, gave a special presentation that outlined the responsibilities of the Director, Operational Test and Evaluation (DOT&E) on testing and evaluating survivability. Additionally, he emphasized the current state of the live fire testing (LFT) and Joint Live Fire programs. Mr. Sayre's presentation was very well-received, and he answered many questions from the students on DOT&E's role in aircraft survivability.

The remainder of the course covered material from the following areas: introductory concepts, threats and threat effects, susceptibility and susceptibility reduction, vulnerability and vulnerability reduction, modeling and simulation. Practical application was given with presentations describing the specific aspects of survivability design for fighters, large transports, and helicopters. Classified sessions were held to discuss current threats to aircraft and recent combat incidents from Operation Iraqi Freedom/Operation Enduring Freedom.

Mr. Chris Adams and Dr. Couch taught a majority of the lessons providing the educational foundation for the course. These lessons essentially walked the students through Dr. Ball's text highlighting key aspects of survivability to give the students a general understanding of the material. However due to the breadth of the survivability discipline, subject matter experts were also invited to share their knowledge of specific areas to enhance the learning experience.

The following subject matter experts provided material for the course:

- Dr. Lowell Tonnessen, the Assistant Director of the Institute for Defense Analyses discussed the assessment of personnel casualties in aircraft programs.
- Mr. Dennis Lindell, Program Manager JASP, discussed the current projects and initiatives being investigated by JASP.
- Lt. Col Rich 'Bart' Huffman from the Air Force Institute of Technology taught radar fundamentals and electronic warfare.
- Dr. Knox Millsaps from the Mechanical and Astronautical Engineering Department, NPS, taught the fundamentals of infrared signatures.
- Maj Bryan Forney, a combat experienced helicopter pilot and a graduate of the NPS, discussed rotary wing infrared countermeasures.

Figure 2 Dr. Mark Couch (left) and Chris Adams (right) discuss the influence of tactics of aircraft combat survivability with 'Spud' Gallop (not pictured), the former Commanding Officer of Navy Fighter Weapons School (TOPGUN) at this year's JASP Short Course.

- Ms. Laurie Mitchell from the Joint Combat Assessment Team (JCAT) provided a classified briefing on current threats to aircraft.
- Mr. Greg Fuchs from the Army Shootdown Assessment Team (ASDAT) provided a classified briefing on recent aircraft combat incidents and an overview of the JCAT.
- Mr. Chuck Frankenberger, the Joint Strike Fighter (JSF) Vulnerability and LFT Lead Engineer, detailed recent F-35 test shots.
- Mr. Gerry 'Spud' Gallop, the former CO of the Navy Fighter Weapons School (TOPGUN), lectured on aircraft tactics and their influence on survivability.
- Mr. Alan Brown, who was the first F-117 Program Manager for Lockheed discussed his involvement in the design of the F-117 and provided several anecdotes on the challenges his team had to overcome.
- Mr. William Dooley from the JSF Office discussed fighter specific aspects of survivability.

Figure 3 Gerry Gallop, Chief Operating Officer of Tactical Air Support, Inc. (TacAir), provided invaluable operator insights into tactics and survivability. His flying operational tours include more than 5000 flight hours in the F-4, F-14, and FA-18, and adversary missions in the F-16N and A-4. His teaching background includes tours as both an instructor and Commander of the Navy Fighter Weapons School (TOPGUN). Pictured above while completing Su-27 flight training in Ukraine during 2008.

Figure 4 Mr. Lou Roncase highlights specific China Lake programs to enhance helicopter survivability.

- Mr. David Legg from the Multi-mission Maritime Aircraft Office at Naval Air Systems Command discussed large transport specific aspects of survivability.
- Mr. Lou Roncase of China Lake discussed helicopter specific aspects of survivability.
- Mr. Barry Vincent of Survivability/Vulnerability Information Analysis Center (SURVIAC), reviewed modeling and simulation and provided an overview of the SURVIAC organization.

Overall, the annual aircraft survivability short course provided a good mix of academic fundamentals and practical application. Over the past nine years that JASPO has sponsored this course, this year's course was judged to be the best by JASP leadership. If you're relatively new to the aircraft survivability community or just want to refresh your knowledge, plan on being in Monterey 15-18 May for next year's course. ■

USAF Combat Damage Incident Reporting: Improving the Process

by Richard Huffman, Jr. and Chris Jerome

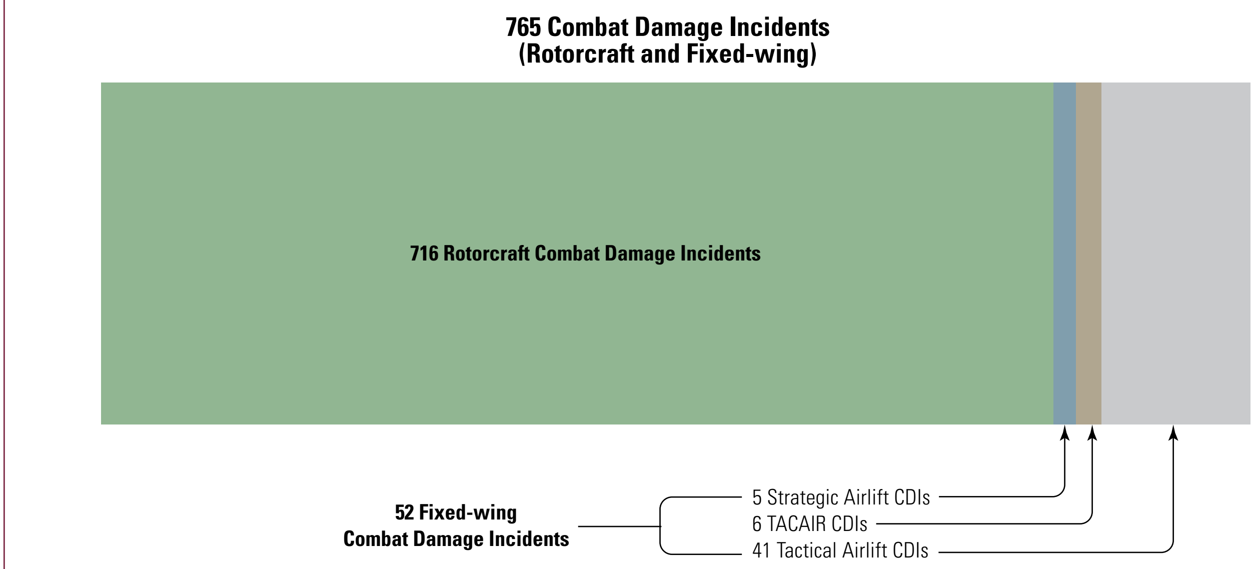
In the US Air Force, changes in organization and doctrine which embrace the Aerospace Expeditionary Force (AEF) construct have had some unintended consequences. One of these consequences is the omission of contemporary aircraft battle damage information from historical records. One of the primary tenets of aircraft survivability is threat definition. Ultimately, this means that the hard working men and women of the aircraft survivability community require timely, accurate, and actionable threat data to make weapon systems safe and effective for the warfighter. To this end, the Joint Aircraft Survivability Program (JASP) works tirelessly through the Joint Combat Assessment Team (JCAT) and the Survivability/Vulnerability Information Analysis Center (SURVIAC) to improve combat damage data collection and analysis.

As seen repeatedly in this journal, JCAT is doing yeoman's work collecting battle damage information in theater. However, they cannot be all places all the time. In fact, they were not originally included as part of the AEF package for Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF). Additionally, Expeditionary Depot Maintenance (EDMX) teams (formerly CLSS) were also left out of the original AEF package for OEF and OIF. These exclusions opened the door for battle damage to go unreported to SURVIAC. Therefore, these facts beg the question, "How many combat damage incidents have gone unreported?"

The quest to answer this question begins with the "Study on Rotorcraft Survivability" discussed by Mark Couch and Dennis Lindell in the Summer 2010 edition of Aircraft Survivability. The rotorcraft study represents, in this author's opinion, one of the most comprehensive sources of aircraft battle damage data available to date. Figure 1 is derived from the same dataset used in the study. For the period covered, a total of 765 combat (hostile action) damage incidents are recorded for both fixed-wing and rotary-wing assets in OEF and OIF. To determine if this data is complete the author needs to find evidence to the contrary. The question remains, how? An independent battle damage database is needed to validate the information presented in the rotorcraft study. Theoretically, corrective actions for aircraft battle damage are captured in an individual aircraft's maintenance records. Thus, to support the hypothesis that battle damage incidents are going unreported, all that is required is to find evidence in the maintenance records that was not captured in the rotorcraft study database, and therefore not captured in SIGACTS/SAFIRE or JCAT Combat Damage Reporting.

To refine the scope of this effort, C-130 maintenance data was examined. The C-130 was chosen because it was involved in the highest concentration of combat damage incidents recorded for OEF and OIF of any fixed-wing aircraft. Yet the relatively low number of incidents, compared to rotorcraft incidents, made for an easier comparison of databases. After exhaustive comparison, analysis revealed at least 10 confirmed combat damage incidents in the maintenance records, which were not captured in the database used to produce the "Study on Rotorcraft Survivability." Thus, the data used to produce the study is missing nearly 20 % of the combat damage incidents involving tactical airlift aircraft. It is important to note this "additional" data supports the overall trends highlighted in the rotorcraft study.

Even though the maintenance data supports the findings of the "Study on Rotorcraft Survivability," without question, the fact data is missing illustrates that the battle damage reporting process needs improvement. The first step in improving the process is to ensure that personnel trained to properly collect battle damage deploy with combat forces. However, as mentioned earlier, JCAT and EDMX cannot be in all places simultaneously. Therefore, a program to institutionalize battle damage documentation should be developed. With funding provided by JASP, SURVIAC has already taken a giant leap with the development of the Combat Damage Incident Reporting System (CDIRS). In this author's opinion, a logical next step is to implement CDIRS as the official battle damage information system for all maintenance units across the USAF. In essence, CDIRS should become an electronic Air Force Technical Order Form 97 (e-AFTO Form 97) on which battle damage information is captured. To normalize CDIRS across USAF maintenance organizations, it is crucial to include CDIRS in the maintenance documentation technical orders and provide the necessary training on how and when the system is to be used. These efforts will ensure that aircraft battle damage information is captured in a timely manner, available for analysis, and can be trusted. Ultimately,



Aircraft Battle Damage Subdivisions

the survivability of future weapon systems depends upon improving the battle damage reporting process. ■

News Notes

Continued from page 5

gave his vision of the role of his office and of LFT&E in support of the warfighter; highlighted numerous contributions that LFT&E is making in current conflicts in Iraq and Afghanistan; and reminded attendees of some of the statutory requirements and issues related to DOT&E's oversight of LFT&E programs. He gave special attention to a statutory change to Title 10 that has resulted in his office's oversight of the test and evaluation of personal protective equipment, such as body armor and helmets. As part of this oversight, his office has helped to develop test standards and protocols, a theme that was expanded upon in a later presentation by his action officer, Mr. Chris Moosmann.

Mr. Sayre also highlighted the Congressionally-mandated test and evaluation of Active Protection Systems (APS), which is being managed by his office. The active protection systems being tested are in various stages of development, and generally are at an earlier stage than most programs undergoing statutory LFT&E. Ms. Stephanie Koch, who is the DOT&E action officer for the APS test program, gave a presentation on the objectives, test planning, and test execution to date.

The conference featured about 40 technical presentations that covered the spectrum of LFT&E interests, including the vulnerability of land, sea, and air systems. Lethality LFT&E of weapons systems was less well represented. A synopsis panel on the last day noted that this conference differed from past conferences primarily in the relative attention given to personnel casualty issues. Panelists considered this understandable given the reality of casualties being experienced in our current conflicts. It's also consistent with current initiatives of Mr. Sayre's office, as presented to the conference.

Mr. Dale Atkinson was honored at the event by the NDIA T&E Executive Committee, which selected him as recipient of the Arthur Stein Award (see related article in this issue). The award is given for outstanding contributions and lifetime achievement in LFT&E. The next LFT&E conference will be held in June 2013 at a site to be determined.

Aircraft Vulnerability to Lasers

The 46th Test Group (46 TG/OL-AC) at Wright-Patterson AFB recently investigated laser effects on fuel-backed aircraft composite materials immersed in a high-velocity airstream. The goal was to conduct a first-ever test of a composite wing box under fully-controlled test conditions that included laser engagement during simulated flight. In order to secure the necessary test approvals, in-lab tests (co-supported by modeling) answered fundamental questions concerning target surface reflectivity, laser burn-through time, and energy absorption due the fluid-backing and the presence of an airstream. Simultaneously, the 46 TG/OL-AC airflow test facility was reconfigured to create a fully enclosed test operation, complete with laser energy blocks. The critical issue was that no laser energy could escape. A laser operations permit was issued to the test range upon conclusion of a series of pretests with lower energy lasers. With permit in-hand, three laser tests were performed on a single composite wing box from an unmanned aerial system. The first two tests avoided the fuel tank and were simply performed to verify laser system stability and burn-through times in the presence of an airstream. The final test involved direct impingement of the fuel tank. Successful completion of the three tests (all conducted within a 24 hour period) served as a demonstration of safe laser operations necessary for future assessments of aircraft vulnerability. The test procedure will now transition to survivability assessments of other military assets against these emerging threats.

Navy reservists in theater improve aircraft performance and survivability and NAVAIR's bottom line

This News Note is courtesy of NAVAIR NEWS.

The Joint Combat Assessment Team (JCAT), comprised of reserve and active duty officers from the Navy, Marines, Army and Air Force, has performed assessments on more than 400 critical aircraft assessments in support of Operation Iraqi Freedom and Operation Enduring Freedom. Navy reserve officers working in support of JCAT's mission to examine aircraft battle damage incidents determine the enemy's weapon systems used in the attack, and their tactics have improved aviator performance and aircraft survivability while supplementing Naval Air Systems Command (NAVAIR) acquisition processes. "The work of our reserve assessors in Iraq and Afghanistan has been critical to making our aviators more effective, our aircraft safer, and our processes better," said Capt. John Slaughter, military director for systems engineering at NAVAIR. "Their work helps us complete more missions, achieve our objectives and bring more people home safely." NAVAIR is responsible for maintaining and improving aircraft survivability during the wars in Iraq and Afghanistan. However, at the start of these conflicts, NAVAIR did not have the capability to perform real-time battle damage assessments. Before JCAT was established, aircraft survivability analysis was based on Vietnam-era data developed by a team of dedicated assessors that was disbanded in the 1970s. JCAT was created with assessors from the Navy and Marine Corps reserve and active duty Army and Air Force. NAVAIR's Reserve Program provides more than 20 officers for JCAT from across the country. "Having Navy reserve officers serving as assessors is a critical component to JCAT's success," said Slaughter. "These talented and dedicated officers bring a wealth of experience and perspective to their time in uniform that allows them to work better with air crews, functional commands and perform well over the wire." Using simple tools – such as a 4-inch, red laminated square card with black rectangular boxes on three edges and a rifle cleaning rod – JCAT assessors look for the facts about each incident. JCAT assessments have three typical components: 1) Assessors interview pilots and air crew to understand the engagement details of incidents. 2) Assessors perform a forensic study of the aircraft, its damage and any fragments. 3) Assessors identify the threat weapon(s) employed in the engagement. JCAT assessors are trained in chemical residue collection as well as warhead fragmentation analysis, weapon part collection, and aircraft survivability equipment; they routinely work with intelligence officers and US-based analysts to determine answers to new challenges or threats. "JCAT's assessors are like crime scene investigators popularized on television programs like CSI and NCIS," said Navy Capt. William Little, JCAT's in-theater officer-in-charge. "We focus on finding the facts, and through the laws of physics and the physical properties of materials, we reconstruct the processes which propagated the damage; compose a report documenting the damage; and, based on available physical evidence, positively identify the enemy weapon that caused it." JCAT's work has enabled the aviation commander to determine the best counter-tactics and ensure the appropriate mitigation measures are employed to defeat the threat. Their findings are provided directly to the warfighters as well as the acquisition and test community, and the Joint Aircraft Survivability Program Office to share lessons learned, archive survivability data and reduce future aircraft vulnerabilities. "The JCAT has provided a specific area of expertise for the G-2 that we otherwise would not be able to match," said Lt. Col. George David, assistant chief of staff, 3d MAW (FWD) G-2. "JCAT determinations have led to discoveries such as the continued use of the .303 Lee Enfield rifle by insurgents for its range and to developing pilot familiarization with threat weapons." "JCAT's work saves lives, which is its most important

US CENTRAL COMMAND -- Navy reserve Cmdr. Steve Mainart inspects damage on a CH-47 Chinook. Mainart is part of the Joint Combat Assessment Team which reviews and evaluates incidents to improve insight on enemy tactics and improve aircraft survivability. The team is comprised of active duty and reserve officers from all services and has performed more than 400 assessments in support of Operation Iraqi Freedom and Operation Enduring Freedom. (US Navy photo)

function," Slaughter said. "But by informing and improving our procurement processes today and in the future, it allows NAVAIR to make smart decisions that not only make the Navy a better fighting force, but saves taxpayers' money at a time of economic crisis and fiscal deficits by ensuring lessons are learned in real-time and that changes are seen before they get too expensive."

Forget CSI, When it Comes to Downed Aircraft, Call SURVIAC

This blog was shared by the Survivability/Vulnerability Information Analysis Center (SURVIAC). It is the 21st in the 22-part series produced by the Defense Technical Information Center (DTIC).

Imagine the following scene: broken glass, bent steel, charred sand, and remnants of a downed US aircraft. Now imagine you are asked to play detective and collect critical information related to the damaged aircraft that will be used to further the Aircraft Survivability community. If this sounds like a scene out of CSI, you'd be close. It's actually a typical scene for the hard working personnel at the Survivability/Vulnerability Information Analysis Center (SURVIAC).

Originally known as the Combat Damage Information Center (CDIC), SURVIAC has been responsible for combat damage collecting, analysis and reporting since its inception in 1984.

Since then, working through the joint services, SURVIAC has accumulated and analyzed over 5,000 incident reports—retrieved from various conflicts—spanning the past 50 years. These reports have been used countless times over the years as a source for validating data, updating Live Fire Test results, and providing feedback to the Acquisition and Engineering communities as well as the Aircraft Survivability community. During current conflicts, as increasingly more aircrafts were shot down and casualties accrued, it became clear that data collected needed a centralized location for storage, analysis and dissemination.

During Operation Enduring Freedom and Operation Iraqi Freedom (OEF/OIF), a joint group of Reserve Air Force, Navy, and Army personnel were deployed forward to gather and process data on aircraft damaged in combat. This was the first full-time deployment for the Joint Combat Assessment Team (JCAT) since its mission began during the Vietnam Conflict. The JCAT approached SURVIAC with the idea of collaborating with the Joint Aircraft Survivability Program (JASP). Shortly thereafter, the Combat Damage Incident Reporting System (CDIRS) was born.

The CDIRS is a classified database containing over 750 high-fidelity investigative reports—most containing high-resolution images, incident videos, crew interviews, and mission narratives. CDIRS is used on a daily basis as a bridge between the forward deployed JCAT units and the Aircraft Survivability Community. As incidents are reported, analyzed and added to the CDIRS, analysts have the ability to access "quick-look" reports (*i.e.,* published within 24 hours) and eventually access full in-depth investigative reports on aircraft damages, crew causalities, and threat assessments.

Through SURVIAC, agencies across the Department of Defense (DoD) have been able to access these reports. SURVIAC's analysis has provided vivid data for R&D efforts, survivability improvements, and feedback for the original equipment manufacturer and program offices. Studies and programs in which these reports have been utilized include the Hostile Fire Detection System, the Common Missile Warning System, the Large Aircraft Vulnerability Study, and the congressionally-mandated Study of Rotorcraft Vulnerability. These reports have also played a critical role in the continual effort to minimize causalities among aircrews in damaged aircraft. Thanks to the joint efforts of SURVIAC and JCAT, vital information regarding Aircraft Survivability is now more readily available to the warfighter.

SURVIAC is one of 10 Information Analysis Centers (IAC) established by DoD and managed by DTIC. SURVIAC is a DoD Center of Excellence responsible for acquiring, archiving, analyzing, synthesizing, and disseminating scientific and technical information related to all aspects of survivability and lethality for aircraft, ground vehicles, ships and spacecraft, to conventional homeland security threats including conventional, directed energy, and asymmetric warfare.

Interested in learning more or working with SURVIAC on an upcoming effort? SURVIAC can be reached *via* the IAC website at *http://iac.dtic.mil.* ■

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Calendar of Events

NOV

Aircraft Survivability Symposium 2011
1–3 November 2011
San Diego, CA
http://www.ndia.org/meetings/2940/Pages/default.aspx

DTIC Fall Workshop
7–9 November 2011
Alexandria, VA
http://www.dtic.mil/dtic

Aircraft Fire & Explosion Course: Vulnerability and Protection in Accidents, Combat & Terrorist Attacks
8–11 November 2011
Woburn, MA
www.blazetech.com/firecourse.html

48th Annual AOC International Symposium and Convention
13–16 November 2011
Washington, DC
http://www.crows.org/conventions/48th-annual-aoc-international-symposium-and-convention.html

AAAA Aircraft Survivability
14–17 November 2011
Huntsville, AL
http://www.quad-a.org

2011 Chemical and Biological Defense Science and Technology (CBD S&T) Conference
14–18 November 2011
Las Vegas, NV
http://cbdstconf2011.sainc.com/general_information/default.aspx

JASP Winter JMUM
15–17 November 2011
Nellis AFB, NV
http://www.jasprogram.org/calendar.html

DEC

EW Payloads on RPA's Conference
7–8 December 2011
Nellis AFB, NV
http://www.crows.org/component/option,com_eventlist/Itemid,537/id,142/view,details

Combat Systems Symposium
12–13 December 2011
Arlington, VA
http://www.navalengineers.org/events/individualeventwebsites/Pages/CombatSystemsSymposium.aspx

JAN

42nd Annual Collaborative EW Conference 2012
24–26 January 2012
Point Mugu, CA
http://www.crows.org/component/option,com_eventlist/Itemid,537/id,146/view,details

FEB

2012 Tactical Wheeled Vehicles Conference
5–7 February 2012
Monterey, CA
http://www.ndia.org/meetings/2530/Pages/default.aspx

MAR

28th Annual National Test and Evaluation Conference
12–15 March 2012
Hilton Head, SC
http://www.ndia.org/meetings/2910/Pages/default.aspx

6th Annual NavExFor 2012
13–14 March 2012
Virginia Beach, VA
http://defensetradeshows.com

APR

JCAT Threat Weapons Effects
17–19 April 2012
Hurlburt Field, FL

MAY

Combat Aircraft Survivability Short Course
15–18 May 2012
Naval Postgraduate School
Monterey, CA

Conference ads and information for inclusion in the Calendar of Events may be sent to:

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Herndon, VA 20171