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The Joint Aircraft Survivability Program (JASP) is pleased to recognize Air Force Lieutenant Colonel (Lt Col) Chad Ryther, personally and as a representative of all the Joint Combat Assessment Team (JCAT) assessors that have deployed to Iraq and Afghanistan, for Excellence in Survivability.
18 OPERATIONAL EVALUATION OF AIR COMBAT EFFECTIVENESS
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To allow weapon systems to be used most effectively when fielded, the Joint Anti air Combat Effectiveness (J-ACE) DVD is providing the Department of Defense (DoD) warfighting community with the means for quantitative operational evaluation of air combat. J-ACE includes a suite of interfaced analysis software application packages, RED and BLUE system performance data sets, a soldier-friendly graphical user interface (GUI), various output displays tools, and an analyst manual.

22 PHYSICS-BASED MODELS FOR INFRARED (IR) COUNTERMEASURES
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Modeling and simulation is an important component in the development and employment of airborne expendable infrared countermeasures (IRCM) to protect military aircraft from hostile missiles. As more sophisticated threats emerge, new countermeasures and techniques are needed to defeat these threats.

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by Joel Williamsen, James Rhoads, and Mark Couch

Traditional approaches to aircraft casualty evaluation within aircraft LFT&E programs have focused on direct threat effects on pilots, treating them as just one of many critical components that could lead to aircraft attrition or mission loss. In 2007, Director, Operational Test and Evaluation’s (DOT&E’s) of LFT&E directed the Joint Aircraft Survivability Program (JASP) to develop and expand tools to predict casualties from all potential casualty sources and identify casualty reduction features.

28 CRITICAL COMPONENT PROTECTION (CCP)INCREASED VULNERABILITY REDUCTION FOR ROTORCRAFT
by Dr. Marc A. Portanova, Nicholas C. Gramly, and Michael C. Breslin

A recent article published in Aircraft Survivability states that the combat hostile action loss rate for aircraft in Operation ENDURING FREEDOM and Operation IRAQI FREEDOM was 8 times lower than that seen in Vietnam. This assertion is supported by data collected in a previously released document, Study on Rotorcraft Survivability Summary Report, and is attributed largely to improved aircraft vulnerability design and the resulting reduction of “cheap kills” caused by small arms and automatic weapon threats.
DONALD W. MOWRER MEMORIAL CONFERENCE ROOM DEDICATED

On 28 March 2013, the SURVICE Engineering Company, headquartered in Belcamp, MD, dedicated the main conference room at its Aberdeen Area Operation to Don Mowrer, an aircraft survivability pioneer, long-time government leader, and former SURVICE Vice President who passed away on 2 November 2012. During the dedication ceremony, which was attended by Don’s family members, friends, and former coworkers, SURVICE CEO Jeff Foulk unveiled a sign and a placard that will hang on the conference room’s wall. Mr. Foulk also highlighted some of the major accomplishments that Don made during his +50-year career in survivability.

Most notably, Don helped to establish survivability as a formal engineering discipline, was a charter member of the Joint Technical Coordinating Group on Aircraft Survivability, and was an early visionary for the establishment of the Survivability/Vulnerability Information Analysis Center and the development of the Computation of Vulnerable Area Tool. In addition, in 1997, the National Defense Industrial Association honored Don with its Lifetime Achievement Award in Combat Survivability.

The 100-person Donald W. Mowrer Memorial Conference Room will continue to be used by SURVICE employees and other government and industry organizations for a wide variety of technical meetings and events. It is located adjacent to the Walter S. Thompson Memorial Library, which SURVICE posthumously dedicated to Don’s fellow survivability leader and long-time coworker, Walt Thompson, in June 2008.

JCAT CORNER

by CAPT Cliff Burnette, Lt Col Doug Jankovich, LCDR Peter Olsen, and Mr. Greg Fuchs, CIV -USA

The casual observer may think that a Joint Combat Assessment Team (JCAT) assessment is merely taking pictures of battle damage, when in fact photos are only one part of a JCAT assessment. A practical way to explain the value of the JCAT assessment activity is to think of Operation ENDURING FREEDOM (OEF) as a large live fire test range. A JCAT assessor collects and documents all of the information available as if he or she were recreating the parameters of the “test” as well as clarifying the effects and outcome of the “test.” All data is captured in a database where engineers and other stakeholders can then review and exploit the event for future design activities. The improvement advantages that are derived from JCAT data can come about in the short, mid- or long-term; they can take many different forms, such as via tactics, techniques, and procedures (TTPs) or maintenance practices, or in the aircraft through considerations such as ballistic protection, system separation, system redundancies, fire suppression, threat countermeasures, or other design changes.

To this end, it is JCAT’s responsibility to:

- Support battlefield commanders by rapidly validating threats that impact combat aviation assets
- Support the Survivability community by documenting aircraft survivability performance data with high fidelity reporting of hostile fire damage to support survivability stakeholder efforts in continuous improvement to sub-systems, systems, and whole aircraft solutions to reduce susceptibility and vulnerability to enemy threat systems

In its critical role, JCAT has recently made significant progress advancing the assessor training curriculum, developing innovative training facilities, and providing survivability engineers with meaningful data. In March 2013 at Naval Air Warfare Center (NAWC) China Lake, CA, JCAT completed Phase 2 training of 30 assessors preparing to deploy. This year’s Phase 2 curriculum included several firsts:

Figure 1. CDR Sean Neally, JCAT OIC conducts assessment at Camp Leatherneck
The amount of field time conducting “hands-on” work significantly increased.

For first time ever, the class participated in a day and night rocket-propelled grenade (RPG) live fire, which provided students an invaluable opportunity to witness the capability and characteristics of the weapon. Both RPG shots were captured in high speed from three views: entrance, overview, and exit.

Figure 2. LCDR(s) Martin performs forensic testing during a JCAT assessment at Camp Leatherneck

Lieutenant Commander (LCDR) Scott Quackenbush and Ensign Mark Buffum considerably advanced another significant JCAT initiative at NAWC China Lake in August 2013 that involved the development of the remote 200+ acre JCAT Training Facility. They facilitated one of the two H-1 helicopters JCAT acquired for training purposes to be shot with two different RPGs for future instruction purposes. Ultimately, the H-1 helicopters and other airframes will be placed in the facility for JCAT students to assess as part of their scenario-based training. When completed, the JCAT Training Facility will feature damaged aircraft based on shoot-down events experienced in Operation IRAQI FREEDOM (OIF) and OEF.

JCAT WARFIGHTER SUPPORT

JCAT-Army, Air Force, and Navy officers continue to support the overseas JCAT mission in OEF. The current OEF JCAT team includes Officer in Charge (OIC) Commander (CDR) Sean Neally and LCDR(s) Calvin Martin at Camp Leatherneck supporting 2d Marine Aircraft Wing (MAW); Major (Maj) Dave Garner supporting the 3 Combat Aviation Brigades (CABs) in Kandahar, Afghanistan; and Captain Gary Roos is supporting the 10 CAB in Bagram, Afghanistan. Every assessor has been busy, especially in the month of August. Lieutenant Colonel (Lt Col) Arild Barrett is in the final stages of preparing for a couple of weeks in theater where he will be assisting the current JCAT-Air Force team with investigations. Lt Col Barrett brings a wealth of rotorcraft and aircraft battle damage repair expertise to the team and his assistance in theater will be welcomed. Likewise, LCDR Jorge Anaya is completing his pre-deployment training with 3d MAW at Marine Corps Air Station (MCAS) Miramar, CA. JCAT-Army supports the soldier forward by providing event-driven rapid response to catastrophic events.

JCAT-Army activities continue at a high operating/operations tempo. While training for deploying units is slowing data—just over 600 deployers trained this FY—the data collection continues with the training imbedded in Army Aviation’s Professional Military Education program. As of July 2013, over 2,500 personnel, from Chief Warrant Officer 1 to colonel, were provided some form of combat damage data collection education. This effort ensures both aircrew and unit staffs understand the JCAT mission.

The Air Force has brought Lt Col Doug Jankovich on active duty to work the day-to-day operations of the JCAT-Air Force. Lt Col Jankovich is handling all training, equipping, and deploying of members as well as reviewing incident reports. Lt Col Jankovich is also planning the JCAT service lead conference that will be held at Wright Patterson Air Force Base, OH from 6-8 September 2013. The purpose of the meeting is to discuss future deployment requirements, training curriculum, special projects, and the 2014 TWE.

JCAT PERSONNEL CHANGES

On the personnel front, the Army component has seen a number of changes. Chief Warrant Officer (CW) 4 Jason Watson has moved to Fort Drum and is deploying to OEF as part of a Brigade Aviation Element imbedded in one of the 10th Mountain Division’s ground combat brigades. On the plus side, JCAT has gained two assessors with recent deployment experience. Both CW3 Brian Bartee, an Apache pilot, and CW3 Rob Olson, a Kiowa Warrior pilot, come to JCAT from the 82d CAB. The biggest transition JCAT faces is the loss of CW5 Bobby Sebren. CW5 Sebren is the only two-time offender, having been the JCAT-Army component’s OIC twice. He split this unique qualification with his deployment to OEF with the 10th Mountain Division in 2011. After over 30 years of service to our nation, CW5 Sebren is retiring; his leadership and technical expertise in everything Army Aviation will be missed. The Army has provided a fitting replacement in CW5 Mike Apple, who comes to us from the 12th CAB, where he was the Brigade’s Command Warrant Officer.

JCAT-Navy CDR Dave Storr reported back for duty as the Navy JCAT Liaison Officer to 3d MAW, MCAS Miramar, CA after a successful second combat tour in OEF. CDR Storr will resume his duties maintaining the JCAT-Navy mission forward, supporting projects at NAWC China Lake and assisting other NAVAIR Reserve Program units with pre-deployment training, logistics, and seamless integration with 2d and 3d MAW. Welcome home Dave and job well done. }
Ballistic vulnerability analyses are highly complicated endeavors that utilize and create voluminous amounts of data. As computing technology has progressed over the years, our ability to handle this type of analysis has improved exponentially. Today’s computers complete these studies, once performed by hand many years ago, more quickly than ever before with an ever-increasing degree of precision.

The availability of improved computing capabilities, however, has increased the chances of introducing unintended errors. With the ability to handle vast amounts of data, analysts have been progressively increasing the precision of their inputs, especially with respect to geometric models. While models are becoming more exact, the amount of information needed to capture the extra complexity in the associated geometry makes it harder for the analyst to manipulate, which may lead to a situation where the model lies outside the theoretical and practical limits of the tools conducting the analysis. A quick comparison of the technological capabilities between aircraft design and ballistic vulnerability tools reveals this risk.

Advances in CAD have greatly reduced the burden of designing aircraft, and the state-of-the-art of these tools progresses rapidly. Companies release updates for their CAD applications (e.g., AutoCAD, CATIA/SolidWorks, and PTC Creo) yearly, providing additional features to facilitate geometry creation and taking advantage of recent improvements in computing technology. Many designers use these tools for visualization and production purposes, so the resulting models tend to be elaborate and include many geometric features, such as rivets, holes, fillets, bevels, ribbing, etc.

In contrast, the ballistic vulnerability community has not developed their toolset to the point where it can effectively utilize intricate, CAD-derived, target models. While the level of detail found in such models generates excellent graphics, their complexity can overwhelm the abilities of community ballistic vulnerability tools (i.e., Advanced Joint Effectiveness Model [AJEM], Computation of Vulnerable Area Tool [COVART], Endgame Framework, etc.) to effectively handle them. In other words, using CAD-derived models in a ballistic vulnerability analysis may not fit the conceptual and processing domains available within these tools.

**CONCEPTUAL LIMITATIONS**

When examining the current community toolset for ballistic vulnerability analyses, two major limitations are readily apparent: 1) the penetration data backing these tools reference far simpler geometries than that which exist on actual aircraft, and 2) these tools depend on ray tracing to interrogate the target.

The first limitation on the ability of ballistic vulnerability codes to handle complex models lies in the conceptual domain of the penetration methodologies. The basis of our current ability to assess penetration is test data. While a vast amount of test data is available after years of ballistic testing, most of these tests have one major limitation: nearly all of the targets were large, flat, uniform plates. The community has done little penetration testing against curved surfaces or surfaces with various features (e.g., ribs, bevels) to better develop existing penetration methodologies. As a result, the current community penetration toolset is best suited when assessing plate-like geometries. Seeing that most CAD-generated models are not typically plate-like, the risk for incorrect penetration assessment increases when using these models.

Beyond the limitations in penetration test data, the community’s use of ray tracing—a common method for interrogating target models—can further lead to errors in penetration assessment. In ballistic vulnerability applications, rays represent the assumed paths of a threat through a target. Most codes use one ray to represent the path of one threat object (e.g., intact missile, projectile, fragment) and assume that intersections with the target model along this ray are locations where the threat will strike target components. This approach inherently limits the understanding of the interactions between target and threat to one dimension. As a result, applications using ray tracing have to make assumptions regarding the surface associated with the intersection. These assumptions are acceptable when the model is relatively simple, but conceptual problems arise as the complexity of the model (i.e., the number of features/elements) increases.

Figure 1 demonstrates how adding complexity to a model may have a substantial impact on penetration assessments. The left side of the plate in the figure is simplistic with no additional features, while the right side of the plate has a sinusoidal tread. If the red and blue rays through the geometry represent threat shotlines, it is evident that threat penetration estimated for the red shotline will differ vastly from that estimated for the blue shotline. The red shotline will
have a single, solid line of sight that will correspond well with the assumptions behind the penetration methodologies. On the other hand, the blue shotline will have multiple smaller lines of sight with higher obliquities that may lie outside the conceptual domain of the penetration methodology employed. Having geometry like that associated with the blue shotline may also have unanticipated negative impacts on other methodologies used within the tools. One example would be the AIRGAP fire assessment methodology in COVART, where the number of intersections between a function and a flammable material are important for fire initiation.

**PROCESSING LIMITATIONS**

Beyond conceptual issues, using CAD-derived geometry models in ballistic vulnerability analyses may exceed the capabilities of the toolset to process them efficiently. The current trend in the community involves converting geometry models, initially in a proprietary CAD format, into code inputs using the “bag of triangles” (BoTs) approach. Undertaking this approach, the analyst exports CAD-derived parts in some non-proprietary intermediate format and then converts the resulting geometry into the input format of the ballistic vulnerability code of interest (typically the Fast Shotline Generator [FASTGEN] or BRL-CAD format). Some of the more popular intermediate formats include the stereolithography (STL), standard for the exchange of product model data (STEP), virtual reality modeling language (VRML), initial graphics exchange specification (IGES), and Wavefront technologies object file formats. While exporting into this intermediate format, the converter redefines the part as a mesh of triangular elements. The number of triangles in this mesh can be quite large (from hundreds to millions of elements), depending on the complexity of the part and desired precision as opposed to the relatively small number of elements (from tens to hundreds) that generally result when recreating the part outside of CAD. Millions of triangles in meshes can have two major drawbacks in a ballistic vulnerability analysis: 1) the amount of time needed to process the geometry increases, and 2) much of the geometric information in the target will not be sampled during the analysis due to gridded ray approach typically employed, resulting in space “wasted” to hold unused information.

As an example, Figure 2 reports COVART runtimes for three simple geometric shapes defined using varying numbers of elements. These shapes, as shown in Figure 3, included a cube, a cylinder, and a sphere. The number of elements used to represent each shape ranged from one primitive representing the geometry to as high as 6.3 million triangular elements. The Survivability/Vulnerability Information Analysis Center (SURVIAC) ran all of the geometry models with

![Figure 1](image1.png) **Figure 1** Two Shotlines, Different Penetration

![Figure 2](image2.png) **Figure 2** FASTGEN Runtimes for Simple Geometric Shapes Represented with Varying Numbers of Elements
COVART using the FASTGEN legacy feature to create shotline output files for a grid of parallel rays with 2-inch spacing. The data points in the figure reflect the clock time necessary for a Windows 7, 64-bit laptop with 2.80 GHz processors and 4 Gb of RAM to process each model. After creating the shotline files for each model, SURVIAC checked to ensure that these results were similar across all models of the same shape. Figure 2 clearly demonstrates that the runtime of FASTGEN increases as the number of elements increases, with runtimes growing more dramatically as this number exceeds 10,000.

Since the triangular elements typically generated with the BoTs approach are small, the likelihood of creating element information that will never be intersected during an analysis increases. In the above example, the box and cylindrical targets resulted in 49 shotlines while the sphere only resulted in 41. Seeing that there could only be two element intersections per shotline, it remains that a maximum of 98 of these elements would have any utility in this analysis. Comparing this number to the maximum number of 6.3 million elements demonstrates that these higher fidelity shape definitions unnecessarily hinder the processing of these geometries from a runtime perspective.

Even with its shortfalls, the BoTs methodology tends to be the favored approach for analysts in the community due to how cost-effective it appears to be for generating geometry for ballistic vulnerability analyses. The less-obvious drawback is that simple parts like fuel lines now require a vast amount of information due to the number and size of elements used. This results in large geometric model sizes that were unanticipated during the creation of the current ballistic vulnerability toolset. No more than a few decades ago, the community would deem a model in the multiple-megabyte range as too large. Now, FASTGEN models have sizes approaching a gigabyte in size with some of the newest models, like that for the KC-46A tanker, reaching the multiple-gigabyte range. The effort that goes into manipulating or maintaining these large files can quickly evaporate any potential cost savings realized in their development.

**ADDRESSING THESE LIMITATIONS**

With this noticeable gap between our ability to design aircraft and our capabilities to assess ballistic vulnerability, the need exists to do one of two things: 1) improve existing tools so that they can effectively handle increasingly complex geometries, or 2) simplify geometries to fit within the domain of the current toolset.

To follow the first approach, the community will need to conduct additional penetration testing against complex geometries as well as build methodologies that can better interpret the geometry impacted on a shotline. As to testing, the feasibility of using curved and complex surfaces is uncertain, and it appears that there are other priorities (e.g., improving existing data sets, increasing materials tested) ahead of moving into this realm. On the methodology side, initial capabilities exist that use multiple rays to account for long or large threats (AJEM and Uncontained Engine Debris Damage Assessment Model), but more work should be done on these methodologies to ensure they are robust and conceptually valid.

Since tools better capable of handling CAD-derived models have not yet arrived, the only recourse in the near-term is to adopt the second approach and simplify geometry inputs to fit the tools. In recent work for various fixed-wing platforms, SURVIAC has determined that a geometry simplification process has three major facets:

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*Figure 3 FASTGEN Models of Geometric Shapes Using Varying Numbers of Elements*
DEVELOPMENT OF MULTIPLE IMPACT TRANSPARENT ARMOR SYSTEMS

by Dr. Marc A. Portanova, Richard M. Delmont, and Michael C. Breslin

Over the past several decades, significant improvements in small arms protection have provided increased protection levels to virtually all Department of Defense (DoD) rotary wing aircraft. Unlike ground vehicles, where the application of high-hard or rolled homogeneous armor (RHA) steel plate is often an acceptable solution, the obvious weight sensitivity of aircraft platforms prohibit such a simple approach. Instead, the use of advanced composite systems have seen widespread application on the DoD helicopter fleet, employing a multitude of materials including ceramics (e.g., silicon carbide, boron carbide, etc.), para-aramids (e.g., Kevlar®), and most recently ultra-high molecular weight polyethylenes (UHMWPEs) (e.g., Spectra Shield II®). Regardless of construct, these composite armor systems have one thing in common: they are opaque. This simple fact often limits the use of armor to opaque areas on a given platform (e.g., seat, floor, etc.). Opaque armor panels have been effectively used inboard of transparent materials (e.g., chin bubbles, down-look windows, etc.); however, they are used at the expense of situational awareness.

The obvious solution to the above dilemma is the use of bullet resistant (BR) glass. Shown schematically in Figure 1(a), BR glass is comprised of numerous layers of conventional glass (float glass) laminated together with a polymer interlayer (polyvinyl butyral/PVB) and backed with a polycarbonate spall shield. While effective at providing small arms protection, BR glass is typically too heavy and too thick for any practical application on most (if not all) rotary wing aircraft. Much like the weight sensitivity issue for opaque armor (described above), the most practical and efficient solution to the transparent problem lies in the use of composite materials.

NEW TRANSPARENT ARMOR TECHNOLOGIES

Recent developments in materials technology have provided a multitude of transparent materials (other than glass) for use in a transparent armor system. Of particular interest are transparent ceramics (e.g., synthetic sapphire, magnesium aluminate spinel, and aluminum oxy nitride) [1], and several advanced polymers (e.g., polyurethanes, polycarbonates, etc.). These materials can be combined in a manner analogous to BR glass systems, resulting in higher performing, lighter weight transparent armor systems.

Figure 1. Schematic Representation of (a) BR Glass and (b) Transparent Armor
Under a recent Aviation Applied Technology Directorate (AATD)-managed and Joint Aircraft Survivability Program Office (JASPO)-funded Technology Investment Agreement (TIA), the above concepts were explored towards the development of an advanced ballistic transparency, capable of sustaining multiple impacts. Working closely with the Department of Energy’s Lawrence Livermore National Laboratory (LLNL) in Livermore, CA, The Protective Group (TPG), located in Miami Lakes, FL, designed and developed a transparent armor system specifically for rotary wing aviation platforms. Described as a Multiple Impact Transparent Armor System (MITAS), the system was optimized not only for weight, but for post-impact visibility.

As is the case for any rotary wing application, weight is the dominant design factor. For MITAS, weight reduction was derived from technology initially developed by LLNL under a contract from the Defense Advanced Research Projects Agency. The LLNL design was based on a different approach than most contemporary transparent armor/BR glass systems. Rather than using numerous layers of glass, where the ballistic threat is literally overcome by the mass of the laminate sheets, an approach more in line with opaque armor design was used. Three primary materials were employed, each of which played a different role in the defeat of the projectile (Figure 1[b]).

First, an advanced ceramic strikeface is utilized, which is typically selected from one of the three ceramic materials identified above. The role of this material is to blunt and/or shatter the incoming threat. Following the hard ceramic strikeface is an alternate material mid-layer, which is typically a thick layer of glass or an advanced polymer (e.g., polyurethane). The function of this layer is to effectively erode and slow down the core fragments and ceramic shard generated from the impact. Finally, much like the BR glass system, a spall shield material is used at the rear of the laminate to prevent fragments from exiting the armor system. While the same polycarbonate used in the BR glass can function adequately for this purpose, materials (e.g., polymethyl methacrylate or polyurethane) may offer some weight savings.

**POST-STRIKE VISIBILITY**

Given the reduced weight architecture, the next objective in designing MITAS was the ability to maintain visibility following a ballistic impact. In traditional glass systems (both BR and non-BR), a catastrophic impact will result in “spider web” cracking throughout the entire window, rendering limited (if any) residual visibility (Figure 2[a]).

For MITAS, an engineered mosaic approach was employed. Shown in Figure 2[b], the strikeface of the window is actually comprised of individual ceramic tiles arranged in a mosaic grid. As can be seen, the effect of this architecture allows for the damage to be contained within the tile that is impacted. Further careful attention is paid to the tile seams and triple points during production, so that damage resulting from impacts to these regions is contained within adjacent cells. The end result is a transparent armor window capable of defeating multiple threats, minimizing collateral damage to the window, and providing the operator situational awareness after the ballistic event.

Given the performance exhibited by MITAS during the course of this effort, AATD/JASPO recommended the MITAS technology to the Department of Defense Research and Engineering Helicopter Survivability Task Force (HSTF) for consideration. The HSTF was established in 2009 as a means of addressing hostile fire threats to rotorcraft, particularly in Afghanistan. Concurrent with HSTF reviewing the MITAS technology, TPG prepared a H-47 down-look window technology demonstrator capable of defeating armor piercing threats (Figure 3). The MITAS technology demonstrator window offered 300% the viewing area and substantially improved multi-hit threat protection (Figure 2) at a ≈17% weight reduction as compared to the legacy system flown on current Army H-47 models.

![Figure 2. (a) Monolithic Transparent Armor Showing Extensive Damage and Spider Web Cracking Due to a Single Shot, and (b) MITAS Showing Reduced Level of Damage after Five Shots (Wwo (2) in the Strikeface Tiles, One at a Tile-Tile Seam, and Two at Tile Triple Point Seams](image)
MITAS was briefed to both the 160th Special Operations Aviation Regiment and PMO Cargo Helicopter. Both expressed interest and became the initial customers for the transparent armor technology. A focused engineering and manufacturing development effort, funded by the HSTF, was awarded as an extension to the existing effort with the intent of providing MITAS windows for the H-47 and H-60 platforms. The MITAS windows would not only be required to meet a revised ballistic specification, but all requirements for an airworthiness release.

Examples of the resultant windows are shown in Figure 4 and 5. The H-47 window features a modular A-kit/B-kit configuration, where the A-kit is installed on the aircraft to allow rapid removal/installation of the armored B-kit (less than 10 minutes based on field trials). The H-60 window is a direct replacement for the current opaque panel and is installed using existing hard-points on the airframe. Windows for all three aircraft platforms were recently displayed at the Army Aviation Association of America Professional Forum and Exposition. Following the meeting, the Air Force expressed interest in the H-60 MITAS window for their H-60 CSAR (Combat Search and Rescue) fleet.

**MITAS FIELDING**

In late 2012, MITAS Low Rate Initial Production (LRIP) was completed for the CH-47, followed by H-60 LRIP for the Air Force CSAR aircraft. To date, 100 MITAS shipsets have been procured for the Army, Air Force, and Special Operations rotary wing aircraft. This technology provides the soldier:

- Theater relevant, armor piercing, and sniper protection
- Multi-hit performance with excellent post-strike visibility
- Improved NVG compatibility (versus legacy systems)
- Greater than 45% weight reduction (versus H-47 variant)
- Increased situational awareness and mission endurance
- Field installability/airframe swapping

**ACKNOWLEDGEMENTS**

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**References**

Conversion—Transforming geometry data from one format to another

Optimization—Simplifying complex geometries and reducing the number of elements

Verification—Identifying that optimized/converted geometries are adequate reflections of the original

SURVIAC has identified or developed initial capabilities for each of these facets and used them to support a ballistic vulnerability study of the HC/MC-130J aircraft. The starting point of this effort was an existing FASTGEN model of the C-130H with an initial file size of 681 MB. While modifying the model to reflect the HC/MC-130J, SURVIAC simplified the geometry, reducing the final target size to approximately 525 MB. This roughly 23 percent reduction in file size led to a 23 percent reduction in FASTGEN processing time, enabling this model to be processed faster than the older C-130H model. Future efforts to develop geometric simplification capabilities will focus on expanding the current toolset and making the process less expensive and analyst-intensive through automation. These plans also include incorporating geometry simplification tools into future releases of the vulnerability toolkit.

In conclusion, while the community attempts to bridge the gap between the complexities of CAD-derived geometry models and the capabilities of existing ballistic vulnerability tools, it should remain mindful of the potential risks of using CAD-derived geometries in ballistic vulnerability studies. While CAD technology creates beautiful pictures, the resulting complexity and volume of data can easily, while unintentionally, exceed the conceptual limitations of the community’s penetration methodologies as well as needlessly slow the analysis process down. Without using simplification in the near-term and expanding our testing and tools to handle increased complexity in the long-term, these complicated endeavors called ballistic vulnerability analyses may unintentionally be providing misleading results.

References


INTEGRATED BATTLEFORCE SURVIVABILITY: BUILDING A BETTER MOUSETRAP

by Lee Venturino, David Black, and William Dooley

The concept of integrated aircraft survivability equipment needs to be expanded to the entire Battleforce structure. In addition to individual platform survivability, the entire strike package must maintain the ability to execute the complete kill chain of detect, track, ID, target, engage, and assess. Survivability becomes even more critical when fifth generation aircraft are operating with their fourth generation cousins and may be called upon to provide an overarching Battleforce protection role. Advanced threats will attempt to disrupt our integrated capability by jamming our global positioning system and Link-16 sensors.

Both the US Air Force and US Navy have realized the importance of ensuring critical tactical information be readily accessible across the Battleforce, regardless of which platform is collecting the information. Both fourth and fifth generation aircraft operating together ensures that threat electronic attack capabilities do not negate our ability to generate a common operating picture for situational awareness, and they prevent targeting information from being shared across the Battleforce. The older fourth generation radars are more susceptible to advanced digital radio frequency memory (DRFM) jamming techniques since, in many cases, they were designed before the threat-jamming techniques were fully developed or known.

As more advanced platforms and radar systems are fielded, the Battleforce must strive to stay ahead of the threat ability to adapt and reprogram their jamming capabilities. Critical nodes in our kill/effects chain can be broken by threat-jamming in certain access denied scenarios. By maintaining an integrated Battleforce survivability posture through the more jam-resistant fifth generation platforms, the Battleforce can maintain our air superiority and dominance. The challenge is to define potential solutions to the threat-jamming waveforms before they have actually been fielded. The F-35 took on this challenge as it developed a process to design electronic protection (EP) features into its active electronically scanned array (AESA) radar. This development activity led to a very robust EP capability that provides a “better mousetrap” to defend against an ever-increasing, threat-jamming capability.

OVERVIEW

Occasionally, over the course of many attempts, a better mousetrap will come along in the acquisition of advanced aircraft capabilities. The mouse, in the form of airborne enemy jammers, must compete to avoid the cheesy kill after navigating through the new radar EP trap. To build the better mousetrap, one must start with a well-defined set of requirements. The clear starting point is to define the mouse; however, there are over 50 different species of mice in the world, and we still do not have full knowledge of all their individual attributes. The enemy jammer operates in exactly the same manner. For self-preservation reasons, enemy jammer designers do not populate their specifications in open literature or Internet accessible sources; therefore, it is nearly impossible to design an EP specification without knowing what the jammer’s whiskers, nose, and tail are about. The Joint Strike Fighter (JSF) Program Office took a different approach to specifying the threat by providing a comprehensive set of design-driving characteristics and asked the contractors to put their best effort in defeating this trap.

THE JSF APPROACH

The F-35 Radar EP team has successfully demonstrated a quantum leap in performance against enemy jammers using a novel acquisition approach designed to meet an advanced threat, while transitioning the most effective techniques to other advanced US radars.
The historical approach has been to design EP systems to defeat hardware-specific threats; however, with the proliferation of DRFMs, jamming waveforms can be changed rapidly and arbitrarily. The historical acquisition process was not agile enough to react to changes and updates to software-based systems. The result typically involved a laundry list of individual jammer waveform reactions, which is a specific response to a specific technique (aka Pavlov’s dogs). Once the jammer changed small parameters on the next sortie due to the full reprogrammability of the pods, the original reaction was made obsolete.

The innovative process for setting requirements was to take a capabilities-based approach to solving the agility issue. The approach was to address the challenge in a holistic manner. This effective holistic approach was the result of a joint government and industry team applying a disciplined system engineering process to defining an effective and affordable EP specification for the APG-81 Radar. This process required prognosticating many years in the future to define multiple potential jammer capabilities and to provide a specification that addresses the attributes of those systems. Unnaturally, this process meant providing a threat description not currently blessed by the intelligence community because a single threat system did not have all of the design driving characteristics. There were, however, tightly-coupled interactions between the program office and the National Air and Space Intelligence Center to ensure the definition was not “unobtanium.”

The F-35 Program Office did not specify a performance requirement in the traditional sense. To be more forward-looking and flexible, they defined a potential future jamming threat with a wide range of postulated, future state-of-the-art performance characteristics. Contractors were expected to address each characteristic, but was not strictly required to design one-for-one countermeasures for each characteristic. Instead, contractors were given flexibility to balance the overall design to meet a broad set of jamming techniques.

To a great extent, this approach requires a high degree of trust between the program executive officer (PEO), the contractors (Lockheed Martin and Northrop Grumman), and the program office engineers. The Joint Program Office (JPO) asked the contractors to put their best effort in defeating the specification with the understanding that the contract specification would not be held hostage if the EP performance was not met 100% of the time. It required trust on behalf of the PEO to accept the risk of developing a capability that has never been developed before on time and on schedule. This JSF process has worked extremely well as Block 2 has delivered much of the radar EP.

**RED TEAM APPROACH TO TESTING**

Once the EP team built the radar, they then deployed a wide range of independent test teams to try to defeat the radar using various jamming systems. These systems included the most advanced jamming systems and jammer designers, and were tested with the F-35 radar in the lab and in flight. The EP team identified and fixed radar vulnerabilities, software errors, and limitations throughout system design and development. Ultimately, the team flew the F-35 radar on an instrumented test-bed aircraft against a multitude of aircraft, radars, and jamming systems at Northern Edge 09 and Northern Edge 11, a joint training exercise involving hundreds of aircraft and ships in a realistic combat training environment.

A comprehensive set of laboratory testing is required prior to deploying to a large force exercise like Northern Edge. Therefore, the JPO invited several jammer teams from industry, Federally Funded Research and development Centers and from international organizations to Red Team against the radar. The benefit of a jointly developed program is attaining best-of-breed practices from other highly sophisticated jamming teams from around the world. Their different worldviews provided a unique series of test and jamming techniques allowing our designers to account for wide variations in jamming approaches.

Large force exercises early in a development program are anathema to most program offices; however, they provide invaluable opportunities to take capabilities out of the lab environment and into a real-world situation that involves real world clutter, aircraft motion, multiple jammers, hostile mountainous terrain, and realistic enemy tactics.

Detailed analysis of the data collected at Northern Edge was completed and indicated that the F-35 radar exceeded expectations. The cost to participate in the exercise was negligible; however, it enabled the performance to be validated 3 years ahead of schedule and in a far more realistic environment than what could have been achieved in a normal flight test. The radar, however, was not infallible. The radar contractor discovered several software bugs, and they were able to fix them prior to delivery to the prime; therefore, by the time the APG-81 is fielded on an
Lt Col Ryther is a combat forensics evaluator with JCAT and currently deployed from Wright-Patterson Air Force Base (AFB), OH to Kandahar, Afghanistan. There, he’s supporting Army aviation operations by providing critical forensic analysis of hostile fire against coalition combat aircraft. Deployed JCAT assessors work closely with the intelligence community as they collect information and contribute to a database that identifies trends on the battlefield and shapes operations. Their joint status helps them interact with each service. The JCAT program selects members who have a strong background in aviation and engineering. Lt Col Ryther’s education and technical background in aeronautical and mechanical engineering make him an ideal candidate for this job. From science and technology in laboratory environments to full up live fire test and evaluation, his career spans multiple areas of the survivability discipline.

Lt Col Ryther is one of a handful of deployed JCAT assessors in Afghanistan and serves as the JCAT liaison officer. Together, the deployed JCAT assessors provide battlefield commanders with key information and tools to fight the enemy by evaluating combat damage and weapons effects. JCAT assessments allow rapid dissemination of threat system information and tactics, techniques, and procedures to the soldier in the area of responsibility. A final report is published for each incident and loaded in the Combat Damage Incident Reporting System database, which is used to enhance the combat survivability of current and future aircraft. From October 2011 until now, JCAT assessors have evaluated 306 combat damage incidents; Lt Col Ryther has assessed 64 of those himself. These assessments typically entail documenting evidence, collecting and analyzing fragments, and interviewing crewmembers.

All JCAT assessors must graduate from a rigorous, three phase multi-service training program funded by JASP. Phase 1, located at Ft Rucker, AL, serves as an introduction to JCAT and focuses on helicopter systems and operations, threat munitions characteristics, and forensic analysis (photography, material failure, weapon dynamics, and physical evidence preservation). Phase II, located at Naval Air Weapons Station China Lake, CA, provides advanced JCAT training and focuses on munitions characteristics (fragments, incendiary, guided, unguided), wreckage

The Joint Aircraft Survivability Program (JASP) is pleased to recognize Air Force Lieutenant Colonel (Lt Col) Chad Ryther, personally and as a representative of all the Joint Combat Assessment Team (JCAT) assessors that have deployed to Iraq and Afghanistan, for Excellence in Survivability.

Figure 1. Lt Col Ryther, right, pieces together forensic evidence of a helicopter shot down by enemy fire in Afghanistan

Figure 2. Lt Col Ryther recovering evidence at a crash site in Afghanistan
Pt Col Ryther’s career began in 1997 when he graduated from the US Air Force Academy with a BS in aeronautical engineering. After spending 4 years in the space and missile community, where he supported numerous activities including restoring mission capability to satellite vehicle failures, Lt Col Ryther began his adventure in the flight test community. In 2001, Lt Col Ryther moved to Barksdale AFB, LA, where he executed the weapon system evaluation program WSEP as a B-52 flight test engineer. This program entailed testing various munitions on the B-52H, including the joint-direct attack munition, air-launched cruise missile, conventional air-launched cruise missile, advanced cruise missile, and the joint air-to-surface standoff missile.

In 2003, Lt Col Ryther moved to Nellis AFB, NV, where he was a flight test engineer on the HH-60G executing developmental, quality, and operational test and evaluation flight test missions on the Pave Hawk. He led flight tests of the upgraded Integrated Electronic Warfare Suite, infrared missile warning, and countermeasures systems. Additionally, he was the flight test engineer for the CSAR-X, replacement for HH-60G, and source selection. He also designed flight test programs to determine HH-60G mishap causes.

In 2006, Lt Col Ryther moved to Edwards AFB, CA, where he became an instructor at the Air Force Test Pilot School (TPS). He taught the application of flight test theory, techniques, and procedures and developed curricula and instructed the TPS Qualitative Evaluation course. Lt Col Ryther was also instrumental in acquiring diverse aircraft from across the Department of Defense and civilian aviation community for the TPS Qualitative Evaluation program.

Lt Col Ryther received his PhD in aeronautical engineering from the Air Force Institute of Technology at Wright-Patterson AFB, OH in 2011. He then became the deputy chief of the Aerospace Vehicle division in the Aerospace Systems Directorate of Air Force Research Laboratory. It was here at Wright-Patterson AFB where Lt Col Ryther was introduced to JCAT, and as the saying goes...the rest is history.
OPERATIONAL EVALUATION OF AIR COMBAT EFFECTIVENESS

by Ronald Thompson, Hugh Griffis, and Josef Seidl

To allow weapon systems to be used most effectively when fielded, the Joint Anti air Combat Effectiveness (J-ACE) DVD is providing the Department of Defense (DoD) warfighting community with the means for quantitative operational evaluation of air combat. J-ACE includes a suite of interfaced analysis software application packages, RED and BLUE system performance data sets, a pilot-friendly graphical user interface (GUI), various output display tools, and an analyst manual. Figure 1 displays an operational view of the J-ACE evaluation capability.

J-ACE is developed by a collaborative team led by the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) and the Joint Aircraft Survivability Program (JASP). Intelligence agencies and technical organizations from across the services provide active support. J-ACE builds on the investment in modeling, simulation, and data made by the acquisition community during the development of fielded weapon systems.

J-ACE OVERVIEW

J-ACE consists of over six million lines of code in modules that are independently designed, built, tested, documented, and maintained. Interface control and application program interface documents are available. Windows, Linux, and Sun operating systems are supported. The basic J-ACE package is classified. Special data sets which are formatted, checked, and tested for use in the Joint Anti Air Model (JAAM) can be made available as required.

The primary J-ACE interface is through JAAM, which is a fast running, two-sided, M versus N simulation of RED and BLUE air-to-air missiles (AAM); RED surface-to-air missiles (SAM); and, RED and BLUE aircraft aero performance. The JAAM GUI supports explicit simulation of air combat engagements. A key output is the probability of missile intercept (Pi).

The Endgame Manager (EM) is a new application that adds missile lethality and target vulnerability. The EM allows explicit evaluation of weapon miss distance, fuse performance, weapon lethality, and target vulnerability. The EM provides the probability of kill given an intercept (Pki).

Providing RED and BLUE system performance data sets for use in J-ACE is a major focus. Source information is collected and then formatted, documented, tested, and configured. An audit trail report is provided which documents each data element and the source. Data are coordinated with their source, which includes BLUE system program offices.

The J-ACE DVD is available to the DoD and DoD contractors. Requests can be submitted to the JTCG/ME through Tinker Air Force Base.
KEY J-ACE APPLICATIONS

The J-ACE JAAM package is widely used across the services to develop:

- Air combat tactics
- For training range SHOT evaluation
- Mission planning
- Acquisition support.

Air Combat Tactics Development:
JAAM is used for US Air Force and Navy tactics and Multi-Command Manual 3-1 development. The JAAM three and pseudo six Degree of Freedom (3 & 6 DoF) kinematic simulations of aircraft and weapons are used to analyze air combat engagement maneuvering and weapons employment. Fidelity is suitable for tactical assessment of pre- and post-merge maneuvers, engagement geometry, effective F-pole (distance from launching aircraft to the target at missile impact) and A-pole (distance from launch aircraft to target when missile active terminal guidance begins) ranges, and engagement outcomes.

Air Combat Training Shot Evaluation:
The JTCG/ME supports a direct software interface between JAAM and mission debriefing systems. The Personal Computer Debriefing System (PCDS) and the Integrated Combat Aircrew Debriefing system (ICADS) are examples which are widely used across the services.

PCDS is a Windows-based mission debriefing software system in which time space position information (TSPI) from aircraft tracking is recorded and replayed to provide a comprehensive operational debriefing capability. During pilot post-flight performance evaluations, JAAM is used to evaluate the effectiveness of missile launches at actual trigger points on the TSPI flight record. To improve pilot effectiveness, the JAAM simulation is also used to consider alternative engagement timing and conditions.

ICADS is currently implementing the JAAM interface for air-to-air evaluation with surface-to-air capability to follow. Ongoing implementation work has the goal of allowing quantitative real-time kill removal.

Mission Planning and Analysis: J-ACE performance evaluation is appropriate for use in mission planning, analysis, and rehearsal. An example is the Enhanced Air Defense Simulation, which has a J-ACE interface for on demand calculation of Pi and Pk/i. This interface supports US Strategic Command analysis of Global Strike mission planning through the evaluation of parameters such as ingress profiles, risk areas, and risk avoidance.

System Acquisition Support: J-ACE is being used in support of the F-35 Joint Strike Fighter (JSF). Application extends from limited support of the developmental test program, to operational test and evaluation (OT&E), through tactics development. Initial coordination to support JSF operations is also underway.

J-ACE PRODUCT DEVELOPMENT PROCESSES

Four key administrative processes are used to leverage work from across the services in J-ACE development:

- The user interface process bounds J-ACE development, beginning with the collection of operational capability requirements and ending with support of J-ACE use when fielded.
- Systems engineering provides a methodical process to efficiently develop an effective product.
- Product management controls development resources, reports progress, and allows timely corrective actions.
- Verification, Validation, and Accreditation (VV&A); and, Approval and Authentication (AA) processes ensure that the J-ACE product provides the best capability available from across the services.

User Interface: Annual J-ACE product development is initiated by a requirements call. A formal solicitation is sent to the services and the combatant commands for data and methodology requirements. Additionally, Operational User Working Group (OUWG) meetings are held where users of J-ACE are brought together to identify requirements. Collectively these top-down and bottom-up surveys are used to define the operational capability that future J-ACE releases will provide.

Systems Engineering (SE): Here the operational objectives defined by the user interface are developed into performance requirements and communicated to the extended J-ACE developmental team. An appropriate functional approach to meeting those requirements is identified; and finally, the physical J-ACE product is developed. The SE process generally consists of product planning, development, test, review, and approval efforts. Each phase and associated milestone provides only what is necessary and possible at that point in development to support follow-on work.

The SE process is applied both at the individual module and the overall product level. The process is tailored to the complexity and scope of each development effort, while structured to allow the right people to explicitly make necessary judgments and decisions when required.
Program Management: J-ACE is released annually. This allows timely intelligence and data updates and fielding of new capability. However, 2 years are required for the complete product development cycle and some complex developments require several years of phased effort. As a result, 2 versions of J-ACE are under development at any given time. Formal planning for future J-ACE development extends at least 3 years. Annual J-ACE funding is provided by the Office of the Secretary of Defense (OSD), Operational Test and Evaluation, Live Fire Test and Evaluation.

VV&A and AA: This is the J-ACE product quality control process. Verification ensures things are correct and are working as designed. Validation confirms results reflect real-world outcomes. The JTCG/ME accreditation documentation process explains the intended applicability of the product, subject to known assumptions, limitations, or errors. Approval is a final quality and administrative review by the Air Force, Army, and Navy JTCG/ME Service Leads, which results in formal authentication of the product for use by that service.

Testing and documentation of results are critical elements of the quality control process. Software and data subject matter experts (SME) conduct developmental testing to verify performance. Hierarchies of developmental tests, which extend from the component to the integrated product level, are conducted. Extensive, ongoing, automated regression testing is done to ensure changes made during development do not introduce errors in previously completed work.

Validation testing is typically done at the performance level. J-ACE is an operational tool. The results of validation testing are compared against engineering level analytical models. The analytical models are in turn validated against the available set of real-world test results.

Product operational testing is conducted to ensure the user interface is appropriate, the integrated product performs as
expected, and provides reasonable results. Operational testing often includes experienced J-ACE Power Users.

**PLANNED J-ACE DEVELOPMENT**

The following paragraphs summarize the J-ACE capability expected in annual releases over the next 3 years.

**JAAM and Aero Performance:** Each J-ACE release provides updated missile fly-out models. Historically, only fielded systems have been provided, but the scope will increase to include near-term future threats. Including future threats enhances J-ACE use in system acquisition and operational test.

Advanced pseudo six DoF BlueMax6 and Hercules aircraft aero performance models will be provided. These models will allow tactics development to take better advantage of the full aircraft capabilities. BlueMax6 and Hercules provide a large library of BLUE and RED aircraft models developed by the acquisition and intelligence communities. JAAM aircraft maneuver scripting using the pseudo six DoF models will be simplified.

A basic suppression of enemy air defenses (SEAD) capability will be provided that allows selected BLUE air-to-surface weapon launch and fly-out against a SAM threat. The PCDS user request for BLUE air-to-surface weapon assessment capability in JAAM will be addressed.

**Target Vulnerability, Weapon Lethality, and Endgame Manager (EM):** Initial EM capability has been fielded. The November 2013 J-ACE version 5.2 release includes data adequate for the evaluation of hundreds of weapon target pairings.

Additional weapon and target data will continue to be provided and updated. The following list describes key ongoing developments:

- Near field blast damage evaluation that does not assume spherical blast propagation
- Legacy pseudo-empirical methodology for evaluation of continuous and discrete rod threats
- Advanced optical, passive InfraRed (IR) and semi-active Radio Frequency (RF) missile fusing

Providing this capability will complete major EM development.

**Electronic Counter Measures (ECM):**

Evaluation of ECM is an important part of air warfare which has been beyond the capability of a fast-running operational tool. However, significant capability is now available and annual J-ACE releases of increasing capability will be provided. The focus is self-protection ECM. Development will leverage available methodologies and empirical data.

The initial scope includes BLUE ECM effects on RED RF and IR AAM and SAM. Follow-on capability will be the evaluation of RED ECM on BLUE RF and IR AAM effectiveness.

Dynamic visualization of an aircraft’s ECM systems’ zones of coverage will allow pilots, while developing threat engagement or evasive maneuvers, to consider ECM protection with respect to the threat position. When more explicit effectiveness evaluation is required, the Enhanced Surface to Air Missile Simulation (ESAMS) and MOSAIC legacy engineering tools (respectively for RF and IR systems), along with the necessary performance data sets, will be called directly from the JAAM user interface.

**SUMMARY**

With annual OSD funding, the J-ACE development team is methodically integrating work and leveraging expertise from across the DoD to provide the quantitative tools required by the warfighting community for optimal application of fielded air combat systems.
PHYSICS-BASED MODELS FOR INFRARED (IR) COUNTERMEASURES

by Caroline Wilharm and Brent Waggoner

Modeling and simulation is an important component in the development and employment of airborne expendable infrared countermeasures (IRCM) to protect military aircraft from hostile missiles. As more sophisticated threats emerge, new countermeasures and techniques are needed to defeat these threats. To support the development of these items, more sophisticated, higher fidelity models are required.

Current models rely on empirical inputs from look-up tables constructed from measured data at limited test conditions (i.e., aspects, speeds, and altitudes). Countermeasures are sometimes represented as spherical sources with time-varying intensities. More sophisticated representations may include multiple spherical sources per expendable that change in size and intensity dynamically.

To add detail to these representations, data from high resolution IR cameras—SuperFrame or Duochrome imagers, which are state-of-the-art for measuring IR events—could be analyzed to develop more sophisticated look-up tables, but these would still be based on empirical data; therefore, they would have no predictive capabilities. Alternately, a physics-based approach can be used to generate imagery for any given set of conditions. Physics-based modeling is a cross-disciplinary field that includes elements of applied mathematics, numerical analysis, computational physics, and computer graphics. This technique enables the development of computationally-based visual models for complex objects based on their inherent physical characteristics.

There are several types of IRCM devices. All such devices function by presenting an additional source of IR radiation to the missile seeker. Each IRCM device type has unique performance characteristics, stemming from different underlying physical phenomena. This Joint Aircraft Survivability Program project addressed two IRCM types: conventional pyrotechnic decoy flares and pyrophoric decoy devices.

CONVENTIONAL PYROTECHNIC DECOY FLARES

The payload of a conventional pyrotechnic decoy flare is a flare grain made from magnesium, Teflon®, and Viton® (MTV). This material is ignited as it is dispensed from the aircraft, resulting in a burning, high-intensity IR source. Flare grain material undergoes combustion in two stages. The condensed phase components at the surface of the grain react to form initial gaseous and fine particulate products that rapidly expand into a fireball. The particulates are carried in the expanding gas that mixes with surrounding air to further react, liberating additional energy. The dynamic motion of the grain through space shapes the plume.

Many efforts have been made in the past to model MTV, particularly its reaction chemistry, at varying levels of detail. Reaction Chemistry—What reactions occur, the heat generated by the reactions, what products are formed along with their concentrations and phases, and the kinetics or rate of the reaction

Mass Transfer—The physical interaction of the reaction products with the surroundings to form the flare plume

Heat Transfer—The conduction of heat into the flare grain to propagate combustion into the flare, and convection and radiation of heat from the reaction zone to the surroundings

The result is a large, highly coupled set of partial differential equations (PDEs).

COMSOL Multiphysics® is a customizable, module-based PDE solver. To use COMSOL, the problem geometry must be defined, a variable resolution meshing must be applied, the physics of the system must be specified, and material properties, source terms, and boundary conditions must also be applied.
then solves the flowfield and provides a visualization of the results—a detailed spatial map of species, temperature, and velocity as a function of time for the burning flare grain. The temperature map shown in Figure 1 illustrates the level of detail that can be generated using such modeling techniques.

PYROPHORIC DECOY DEVICES

A pyrophoric decoy device contains pyrophoric metal. The material reacts very quickly with air, liberating large quantities of heat, which gives an IR signature. To model this type of device, two main events must be described: the dispersion of the material into the air and the heating that occurs.

To model the heating of the material, the physical properties of the material must be defined, including macroscopic dimensions, a mathematical description of the porous structure, and the physicochemical properties of the metal. Mass and energy balance equations must be established to describe the interaction of the material with its surrounding environment. Numerical methods must be used to solve this set of coupled differential equations, yielding the temperature of the material as a function of time, for a given set of conditions at the time of dispense.

The material can then be given a trajectory. Naval Surface Warfare Center Crane is working with aerodynamics teams from the US Army Aviation and Missile Research Development and Engineering Center (AMRDEC) Aeroflightdynamics Directorate (AFDD) and Naval Air Systems Command Naval Air Station Patuxent River to develop detailed aircraft flow fields using computational fluid dynamics. These flow fields are being used to create high-fidelity models of the spatial distribution of the material. Figure 2 shows a sample flow field.

IMAGERY GENERATION

The IR scenes needed for missile-flare engagement models must contain detailed representations of the aircraft, backgrounds, and countermeasures. Most Department of Defense activities doing missile effectiveness studies are migrating to the Fast Line-of-Sight Imagery for Target and Exhaust Signatures (FLITES) software, produced by Kinetics, Inc. Figure 3 shows a sample image from a FLITES run with a detailed aircraft and pyrotechnic countermeasures.

SUMMARY

This effort is the first integration of countermeasure combustion, thermodynamics, spectral emission, and trajectory programs to render a representative scene. It will provide a new class of models for expendable IRCM to be used in both current simulations and those being derived for advanced seekers. This new class of physics-based countermeasure models will have the ability to predict the behavior and performance of countermeasures that have not yet been fabricated. This effort will greatly reduce both countermeasure design optimization
Increasing model fidelity has the potential to reduce or eliminate a significant portion of flight testing for countermeasure development. Ultimately, these increased fidelity models have great potential to improve countermeasure effectiveness, which will better protecting our soldiers.

References


AWARD WINNING RESULTS

The F-35 Radar EP team won the David Packard Excellence in Acquisition award in 2010 for its novel approach to acquisition. The F-35 sensor-fused radar environment will provide US and coalition soldiers with a distinct advantage over enemy aircraft for the foreseeable future. The definition of the mousetrap was initially fraught with problems, but at the end of the day, the trap once again ensnared the cheese-seeking jammer.
A POTENTIAL AIRCRAFT CASUALTY EVALUATION APPROACH FOR LIVE FIRE TEST AND EVALUATION (LFT&E)

by Joel Williamsen, James Rhoads, and Mark Couch

Traditional approaches to aircraft casualty evaluation within aircraft LFT&E programs have focused on direct threat effects on pilots, treating them as just one of many critical components that could lead to aircraft attrition or mission loss. In 2007, Director, Operational Test and Evaluation’s (DOT&E’s) of LFT&E directed the Joint Aircraft Survivability Program (JASP) to develop and expand tools to predict casualties from all potential casualty sources and identify casualty reduction features. In the intervening years, JASP developed Crew and Passenger Survivability (CAPS) casualty assessment methodologies, and demonstrated the CAPS methodology in part for H-60 and C-130 (although additional refinement is needed). An FY14 JASP Roadmap task is planned to outline test data and model development needs for evaluation of personnel casualties.

Table 1 shows the number of casualties (fatalities and injuries) from Department of Defense (DoD) rotorcraft combat damage incidents from October 2001 through August 2012. The fatalities were grouped in four broad categories:

1. Those that were a result of threat effects directly hitting the person
2. Those that were a result of a catastrophic crash
3. Those that were a result of a survivable crash
4. Those where the cause of the fatality is attributed to both threat impacts and crash effects

Although more detailed causes for fatalities are possible, they were not seen in the available post-crash evidence. Examples include cascading effects from secondary fires aboard the aircraft before a crash occurs and a failure to egress the aircraft following a crash.

This article outlines a standardized casualty assessment approach for rotary and fixed wing aircraft that supports the development of the JASP casualty assessment roadmap; with terminology and metrics that are consistent with combat data such as that shown above; already existing aircraft vulnerability data.

Table 1 DoD Rotorcraft Fatality and Injury Data (October 2001 to December 31, 2012)

<table>
<thead>
<tr>
<th>Cause of Casualty</th>
<th>Combat Hostile Action Fatalities</th>
<th>Combat Hostile Action Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pilot</td>
<td>Pax/Crew</td>
</tr>
<tr>
<td>Threat Directly Hitting Person</td>
<td>23</td>
<td>45</td>
</tr>
<tr>
<td>Catastrophic Crash*</td>
<td>26</td>
<td>58</td>
</tr>
<tr>
<td>Survivable Crash**</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>Threat and Crash†</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>Unknown</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>63</td>
<td>139</td>
</tr>
</tbody>
</table>

* A catastrophic crash is defined as one where the aircraft impacts the surface (land or water) under conditions of attitude and velocity that do not permit the survival of any of the crew members, even when considering all available crashworthiness features that help lessen the impact forces (e.g., hitting the surface at severe pitch or roll attitudes or at high speed such as in controlled flight into terrain).

** A survivable crash is defined as one where the aircraft impacts the surface (land or water) under conditions of attitude and velocity that allow crashworthiness features to help lessen the impact forces, and other damage cascading effects, to the extent where at least one crew member might survive.

† A threat and crash is defined as one where the occupants have both threat and crash injuries to them and the cause of the casualty is both.
and models; the JASP CAPS methodology; and the Army’s Full Spectrum Crashworthiness criteria.

**DEFINITIONS**

“Casualty” is broad term that can include both fatalities and injuries. At a minimum, an aircraft crew casualty assessment should include fatalities and use methodologies that adequately predict fatalities so that suitable casualty reduction techniques can be applied. Assessing the extent of injuries may vary significantly from aircraft to aircraft, depending on the mission, the number of crew and passengers, and their seating locations in the aircraft. The extent of injury assessment will be defined for individual programs in cooperation with DOT&E; however, considering the potential for aircraft fires shortly following crash landings or landings where fuel is leaking (near hot engines), casualty evaluations should include any injuries that lead to an inability to safely egress the aircraft following landing.

The possibility of casualties is greatly affected by the end state of the aircraft. Consequently, the proposed approach defines three possible outcomes of the aircraft:

- **Outcome I:** Immediate Loss/No Control—The aircraft has a total loss of control and will crash catastrophically with the loss of all crew and passengers.
- **Outcome II:** Degraded Capability—Includes crashes, forced landings, or air egress
- **Outcome III:** Return to Base—A crash does not occur, but other casualties are possible nonetheless.

Within each of these outcomes, up to four casualty categories should be determined:

- Direct casualties from threat effects impacting occupants
- Cascading casualties from indirect explosions, cabin fires while in the air, or other delayed effects prior to a landing attempt
- Crash-related casualties from structural deformation of the aircraft or from seat failure
- Egress casualties due to the inability to egress following landing, ditching, or ejection/bailout (includes post-crash fire effects).

Mapping of the three possible outcomes to the four casualty categories is shown pictorially in Figure 1. Within the outcomes, “t” refers to time, and “tcrit” is defined as the time at which the aircraft experiences immediate loss or total loss of control, allowing no additional time for air egress and meaning the aircraft will crash catastrophically. The term “tbase” refers to the time required to fly back to base (e.g., the point of departure or intended landing location) and conduct a normal landing. Direct and crash casualties can

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**Figure 1. Recommended Aircraft Outcomes and Casualty Types to be Considered in Aircraft Casualty Assessments**
Cascading and egress casualties can occur for Outcomes II and III, and crash casualties are not considered in Outcome III. Outcome II is considered the most difficult outcome to assess since it includes all four casualty types.

EVALUATION METHODOLOGY

Casualty evaluation begins with the definition of a threat and vignette that is consistent with a larger integrated survivability assessment, which includes mission type, phase of flight (e.g., takeoff, cruise, landing), definitions for time to a safe landing at base, flight profile (e.g., altitude, airspeed), and flight conditions (e.g., payload, fuel load). For selected vignettes, the program should perform a vulnerability assessment with a distinctive critical item list for each potential aircraft outcome, taking into account the individual aircraft attributes. The relative likelihood of each outcome may set the scope of the overall casualty assessment, which is a matter of negotiation between DOT&E and the program of record. For example, if the relative likelihood of Outcome II is considered low or is made low through vulnerability reduction or crashworthiness features, a detailed crash casualty assessment might not be required for Outcome II.

Direct casualties would be assessed through the combined use of existing aircraft vulnerability models and established casualty criteria. Cascading casualties would be assessed by identifying the source of casualties (usually explosive or fire producing cabin materials) and developing tests and models to predict the hazard level to passengers and crew, the hazard radius (of effect from the hazard site), and the time required for critical damage thresholds to be reached compared to the time needed to extinguish fires or land the aircraft. Fire suppression systems designed into the aircraft have the potential to lower both the probability of fire and the hazard level created. Personal protection equipment, such as smoke hoods and oxygen masks, that is readily available or required to be worn at all times could increase occupant survival time relative to the time needed to land the aircraft, potentially reducing cascading casualties.

Egress casualties can include air egress (considered under Outcome III) or land/sea egress (within Outcomes II and II). Air egress casualties are determined through examining the ejection/bailout envelope of ejection systems compared to vignettes of interest. Land egress losses are assessed by first determining the probability and severity of post-crash fires (including pool fires) through exterior models or tests, then determining the time available to egress the aircraft through specialized testing, considering day/night, soldier equipment, blockage, and presence of injuries. If egress time is greater than the critical hazard development time, a casualty can occur. The number of casualties will be related to the number of occupants failing to egress before critical hazards occur.

Evaluations of casualty-reducing technologies are possible throughout the evaluation process. Aircraft solutions include traditional vulnerability reduction measures (to prevent a crash), improved crashworthiness features, cabin fire suppression, cabin lighting, and improved equipment storage. Personnel solutions include hoods, oxygen masks or other breathing assists, body armor, and improved ejection systems. Improved tactics, techniques, and procedures, such as improved egress procedures and training for crash events, may also be employed to reduce casualties.

POTENTIAL LIVE FIRE ISSUES

The following live fire issues parallel the three outcomes and four casualty categories described above:

- What are the likelihoods of the following aircraft outcomes following attack?
  - Immediate loss or total loss of control
  - Degraded capability (landing attempt short of base)
  - Return to base/controlled landing

- What are the estimated casualties following attack in each of the following categories?
  - Direct crew and passenger casualties

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CRITICAL COMPONENT PROTECTION (CCP)

Increased Vulnerability Reduction for Rotorcraft

by Dr. Marc A. Portanova, Nicholas C. Gramly, and Michael C. Breslin

A recent article published in Aircraft Survivability[1] states that the combat hostile action loss rate for aircraft in Operation ENDURING FREEDOM and Operation IRAQI FREEDOM was 8 times lower than that seen in Vietnam. This assertion is supported by data collected in a previously released document, Study on Rotorcraft Survivability Summary Report[2], and is attributed largely to improved aircraft vulnerability design and the resulting reduction of “cheap kills” caused by small arms and automatic weapon threats. Further analysis of this data suggests that the number of fatalities resulting from catastrophic crashes (other than mishaps) exceeds the number of fatalities resulting from a direct hit on an aircraft occupant.

Practically speaking, this data indicates a simple trend: current aircraft occupant protection systems (e.g., Ballistic Protection System [BPS]/BAPS), Enhanced Ballistic Protection System [EBPS], etc.) are effective. The occupants of the aircraft are better protected now than in previous conflicts. Crashes, however, have now become the dominant cause of fatalities for rotary wing aircraft. There are two primary means to reduce these fatalities:

1. Improve aircraft crashworthiness
2. Reduce the effect of the aforementioned “cheap hit” on an aircraft’s critical systems (in which a successful hit would result in a downed aircraft)

It is the latter that will be the focus of this article.

LEGACY ROTORCRAFT PROTECTION

BPS/BAPS and EBPS have been deployed and/or are currently in use on numerous platforms, including Hueys (UH-1), Chinooks (CH-47), Blackhawk Fleets (UH-60 and MH-60), and the Super Stallion (CH-53E). These systems date back to the late 1990s/early 2000s, first surfacing in response to the needs of the 160th Special Operations Air Regiment and as a replacement for the ill-fated BASS (Ballistic Armor Sub System). Unlike BASS, which was ceramic-based and lacked durability, the original BPS was a metallic composite capable of providing the desired level of protection and an extremely long service life. Similar to BASS, the BPS attached to the floor of the aircraft and provided “bulk” protection to the occupants of the cockpit and cabin.

More recent versions of BPS (e.g., AOBPS, EBPS, etc.) feature similar levels of protection at a reduced weight due to the use of ultra-high molecular weight polyethylene (UHMWPE) (e.g., Spectra Shield®) as the core of the system. While the previously noted report confirms the effectiveness of these occupant protection systems, the data continues to indicate an unacceptable level of fatalities. This simple fact became the impetus for Army Aviation Applied Technology Directorate (AATD)-managed, Joint Aircraft Survivability Program Office (JASPO)-funded critical component protection effort described in the next section.

CRITICAL COMPONENT PROTECTION (CCP)

The concept of CCP is not new to aviation; however, the ability to protect critical flight systems in a weight-economical means has been a challenge. As evidenced by the BPS family of systems, most lightweight (i.e., composite) armor systems are flat. This is a result of the fact that most materials used in these armor systems (e.g., ceramics, para-aramids, UHMWPEs, etc.) require high consolidation pressures at some point in their manufacture; therefore, historically, the use of flat or large radii of curvature panels to protect critical components was the primary solution available, resulting in bulky, ineffective, and heavy protection.
As part of this effort, The Protective Group (TPG), located in Miami Lakes, FL, was tasked to demonstrate a combination of mature materials and manufacturing technologies which, when put together, could provide a means to produce complex shape, high degree of curvature, and high performance armor composite parts without using high pressure processing and incurring significant cost or weight above traditional flat panels. Two platforms were focused on for this effort, both of which have critical component areas of high vulnerability: AH-1 Cobra and OH-58D Kiowa Warrior.

**NEAR NET-SHAPE FORMING TECHNOLOGIES**

To achieve the overriding goal of this effort, a number of unique, near-net shape ceramic, metallic, and polymeric rapid-fabrication technologies were investigated. While numerous technologies were identified that were capable of providing the necessary design and performance features, two technologies were focused on based on the requirements of the platforms:

1. Reaction bonding of complex-shaped, monolithic ceramic components
2. Direct composite integration

**Reaction Bonding of Complex-Shaped, Monolithic Ceramic Components**

Reaction-bonded ceramic materials have been used in industrial applications for over 50 years. Following the attack on the US in 2001 and the subsequent wars, these materials saw a rebirth for use in body armor. M Cubed Technologies (MCT), located in Newark, DE, has become a leader in this technology, pushing the performance of reaction-bonded boron carbide (B4C) and silicon carbide (SiC) [3,4] materials well beyond that of many of their hot pressed competitors. One of the key advantages of MCT’s process is their ability to fabricate complex shaped and/or large, monolithic ceramic components. This fabrication allows large areas to be protected using a single piece of “tough” ceramic, rather than a tiled approach used in conventional armored designs.

**Direct Component Integration**

In nearly all advanced, lightweight armor solutions available today, some form of fiber-based composite material (e.g., para-aramid, UHMWPE, etc.) is utilized in a spall liner/backing system. The two primary methods used to process these components in hard armor systems are high-tonnage pressing and autoclave consolidation. Due to the much higher ballistic performance usually associated with high-tonnage pressing, it is the process most typically used in modern hard armor systems. Consequently, autoclave consolidation has been seldom used in these systems. It is worth noting, however, that the high-tonnage processing route requires a second process step (in an autoclave) in order to bond the strike face component to the fiber-based backing material. This secondary reheating of the pressed backing reduces its ultimate performance, reducing the performance gap between the two processing methods.

TPG, under a concurrent ONR effort [5], developed a technique whereby the fiber backing system is directly integrated within the system via autoclave processing. Through unique materials architectures and processing techniques, the performance of the directly integrated system is virtually the same as that of the high-tonnage approach. By invoking this technology, the entire armor system can be integrally processed in a single autoclave process cycle.

One of the major benefits to the direct integration autoclave approach is the dramatic reduction in tooling costs. Unlike the high-tonnage approach that typically requires billet-machined aluminum or stainless steel tooling, the direct integration approach can employ the rigid system components (e.g., structural metallics and/or strike face ceramics) as the tooling. For example, in a ceramic-based armor system (specifically one that makes use of a reaction bonded, complex-shaped monolithic ceramic tile), the ceramic component, itself, acts as the tool. By using this methodology, the path to prototype (and then production) is significantly shorter and less expensive (and less risky) than it would be in high-tonnage pressing.

**OH-58D KIOWA WARRIOR**

Following the selection of the OH-58D platform for this demonstration effort, and upon further discussion with the program office, the engine access door was identified as a candidate component (Figure 1). The current door is outfitted with two flat armor panels that are attached on the inboard side of the door. By combining the two materials technologies described above, these panels could be better integrated into the door structure, reducing overall weight and/or improving protection.

After multiple rounds of iterative design and live fire testing, a ballistic defeat solution was developed that could provide the same level of protection at a substantially reduced weight. This weight savings was applied to the area of protection, resulting in a solution that not only covered 51% more area than the legacy design (at the same weight), but
also provided protection against a more aggressive range of attack angles due to the curvature of the panel (Figure 2).

As a means of further enhancing the potential weight savings, it was suggested that the aluminum door be replaced by one made from carbon fiber. While outside the scope of this effort, it is estimated that an optimized door structure would reduce the component weight by approximately 15%. A rough mock-up of the door was fabricated from carbon and the actual armor panel was attached for validation testing (Figure 3).

To verify that ballistic performance was maintained in the full-scale part, the prototype (while mounted to the mock-up door) was impacted twice by the OH-58 specified threat. The armor areal density was 6.3 lbs./sq. ft. (PSF), which, at this protection level, equates to a mass efficiency of 3.32. The successful test concluded the CCP effort demonstration on the OH-58 platform.

**AH-1Z Cobra**

Admittedly, the OH-58D application of the CCP armor concept did not exercise the full capability of the technology.

While considered a successful demonstration, the complexity of the part was minimal. Through initial discussions with Naval Air Systems Command (NAVAIR), it became apparent that the AH-1Z would be a better platform on which to demonstrate the technology. The specific area to be protected was the bell crank housing located on the starboard side of the aircraft, below and approximately between the pilot and copilot seats. The nature of this location as well as the AH-1 threat protection requirements made it necessary to design an armor system of a much higher complexity and curvature.

For the sake of this effort and to reduce a number of security issues, an AH-1S was used to model the area requiring protection. Although the AH-1S is no longer flown by the US military, they are readily available at the Army Research Laboratory, Survivability/Lethality Analysis Directorate (ARL/SLAD). The bell crank areas on several AH-1S models were digitally scanned as a means of creating a digital model of the CCP component. A rapid prototype was produced from the digital model and used to fit-check the design. Once the CCP design was confirmed, a reaction bonded boron carbide strikeface was created and backed using the direct component integration approach. The completed system was mounted on a retired AH-1S at ARL/SLAD and subjected to live fire testing (Figure 4).

Results of the ballistic testing were positive, with multiple rounds being defeated in each panel. As shown in Figure 5, the back face deformation did not interfere with the control rod—a requirement of this system.

**CONCLUSION**

The prevailing benefit of this effort is that it provides clear evidence that small, complex, lightweight armor components can be designed, developed, and implemented in relatively short time frames and inexpensively. It also serves as a blueprint for the execution of similar design efforts in the future.
Figure 5. AH-1S CCP Live Fire Test Results. Note: Back face deformation did not interfere with the control rod/bell crank assembly.

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REFERENCES


A POTENTIAL AIRCRAFT CASUALTY EVALUATION

continued from page 27

- Cascading crew and passenger casualties
- Crash-related crew and passenger casualties (considering hard surface, soil, and water landings)
- Egress crew and passenger casualties

CONCLUSION

This article outlines a standardized, conceptual aircraft casualty evaluation process that may be applied to existing aircraft or future programs of record. Its implementation would require the establishment of new data items to be specified in the live fire strategy, including seat failure and airframe collapse data based on vertical and horizontal aircraft impact velocity into hard surfaces, soil, and water. Casualty evaluation also requires specialized testing, including flight simulations with damaged equipment, cabin interior environment following the onset of fire, egress tests of equipped occupants, and the use of safety-related aircraft data. The casualty evaluation described here can be tailored by taking into account early vulnerability assessments (for aircraft Outcomes I, II, and III), and should make use of both qualitative and quantitative elements where needed.

The authors look forward to participating with JASP and aircraft programs in further refining tools and methods for evaluating and reducing aircraft crew and passenger combat casualties.
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NOV

2013 Homeland Security Symposium
7–8 November 2013
Washington, DC
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10th Annual Disruptive Technologies Conference
13 November 2013
Washington, DC
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DEC

I/ITSEC 2013 (Interservice/Industry Training, Simulation & Education Conference)
2–5 December 2013
Orlando, FL
http://www.iitsec.org/Pages/default.aspx

The Seventh Triennial International Fire & Cabin Safety Research Conference
2–5 December 2013
Philadelphia, PA

2013 Land EW Conference
10–11 December 2013
Quantico, VA
http://www.crows.org/details/223-landew.html

Building Survivable Weapons platforms and More Effective Weapons
10–12 December 2013
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http://www.survice.com/

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http://www.blazetech.com/resources/pro_services/FireCourse.pdf