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AIRCRAFT SURVIVABILITY

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JAS
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After almost 30 years of working in the survivability discipline, I have seen a lot of changes. Some changes were positive, others…you be the judge. I have had the privilege to work on several fighter aircraft programs, including the F-16, F-22, and the F-35.

The US Army's Aviation Development Directorate (ADD)–Aviation Applied Technology Directorate (AATD) executed a project to evaluate and select technology for enhanced aircraft and crew/occupant protection, improved durability, and reduced environmental vulnerability in an integrated, platform-level prototype without impacting mission performance. In the project, entitled Integrated Aircraft and Crew Protection (IACP), threats to aircraft and occupants were defined, vulnerability to those threats was quantified, and technologies addressing those threats were identified.

There has been a series of commercials for BASF, claiming we do not build the systems you use, we make them better. Over the years, the Survivability/Vulnerability Information Analysis Center (SURVIAC) has had a similar mission—not to build platforms, but to make them survive better. Through those efforts, several platforms have been made more survivable. The one key person in that success has been Donna Egner.

The Joint Aircraft Survivability Program (JASP) takes great pleasure in recognizing Dave Legg for Excellence in Survivability. Dave has most recently been appointed as the Fixed Wing Aircraft Branch Head in the Combat Survivability Division (AIR-4.1.8) in the Systems Engineering Department, Naval Air Systems Command (NAVAIR), where he heads analytical and test organizations that develop survivability requirements for new fixed wing platforms and work on survivability improvements for aircraft currently in the fleet.

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On the cover:
The F-35 Lightning II makes its first appearance March 10, 2014, at Luke Air Force Base. The aircraft was flown in directly from the Lockheed Martin factor at Fort Worth, Tex., and is the first of 144 F-35s that will eventually be assigned to the base. (U.S. Air Force photo/ Staff Sgt. Darlene Seltmann)

19 NDIA LIVE FIRE TEST AND EVALUATION (LFT&E) WORKSHOP

by James O'Bryon

Washington, DC was the site of the recent NDIA LFT&E Workshop, an event held every 2 years and sponsored by the Test and Evaluation Division of the National Defense Industrial Association (NDIA). This workshop was the eighth in a series of live fire workshops dating back to the kick-off event hosted at the Lawrence Livermore National Laboratory in 1988. Due to the nature of the topics, this workshop was again held at the Secret/US Only level.

22 COMPUTER SIMULATION OF A RUNNING AIRCRAFT ENGINE IMPACTED BY A MISSILE WITH WARHEAD

by Sunil Sinha, Gregory Czarnecki, and Ronald Hinrichsen

In this paper, an attempt is made to analytically predict damage to a running turbofan jet engine hit by a missile. The predictive methodology is based upon developing a LS-DYNA® finite-element model of the entire engine as well as the exploding missile. The analytical simulation considers both the effect of ballistic energy as well as the pressure pulse generated as a result of detonation of the warhead in the missile. The engine model accurately captures the complex dynamic effect of transient imbalance forces and gyroscopic moments caused in a dual concentric rotor system spinning at two different speeds.

26 IF IT AIN'T BROKE…TRY TO MAKE IT BETTER?

by Kevin Crosthwaite

Almost 30 years ago, a new government institution was created. The Survivability/Vulnerability Information Analysis Center (SURVIAC) came to be through the active advocacy of the Joint Technical Coordinating Group on Survivability—now the Joint Aircraft Survivability Program—led by Dale Atkinson and the Joint Technical Coordinating Group for Munitions Effectiveness, led by John Blumquist. SURVIAC came into being as a government-owned, contractor-operated center of excellence, hosted at Wright-Patterson Air Force Base (WPAFB), under a contract with the Defense Technical Information Center (DTIC). Booz Allen Hamilton was the original contractor, and has been the only prime contractor to operate SURVIAC throughout that time. Contractually, SURVIAC was a follow on to the Combat Data Incident Center and the Aircraft Survivability Model Repository.

28 THE SURVIVABILITY TECHNICAL COMMITTEE

by Jaime Bestard

This year marks the 25-year anniversary of the Survivability Technical Committee (SURTC) of the American Institute of Aeronautics and Astronautics (AIAA). Founded in 1989 by a group of survivability experts, the SURTC was created to promote the development of survivability as a design discipline for both air and space systems. It is composed of a diverse working group of professional members from academia, industry, and government, representing the aircraft (fixed and rotary wing) and spacecraft communities. Its members provide subject matter expertise in diverse applications of the survivability discipline.

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NEWS NOTES

By Dennis Lindell

JOE MANCHOR RETIRES

Mr. Joseph Manchor retired after more than 38 years of federal service. Joe began his illustrious career by graduating with a BS in aerospace engineering from the US Naval Academy in Annapolis, MD, then spending 11 years as a naval flight officer on the world's premier anti-submarine warfare aircraft, the P-3 Orion. He also served during Desert Storm on the USS Ranger, specializing in aircraft carrier defense and tactics. Joe left active duty in 1992, joining the Navy Reserves, where he was assigned to a Reserve UAV Unit and received experience in UAV logistics and operations.

In 1994, after receiving an MS in mechanical engineering from Pennsylvania State University, Joe went to work for the Naval Air Warfare Center Weapons Division (NAWCWD) in China Lake, CA. He ended up finding his niche within the Survivability Division's Vulnerability Test Branch. Joe's contributions towards survivability and vulnerability reduction (VR) for the next 18 years included serving as the—

- Lead (Navy) engineer for a number of important live fire test & evaluation (LFT&E) programs (VH-71, CH-53E HLR/JLF, MH-60 R/S, V-22, AV-8B). For Joe's outstanding engineering, test, and managerial capabilities, the V-22 LFT&E Program is widely recognized as one of the best LFT&E programs ever carried out by a service.

- Committee Chair for the Joint Aircraft Survivability Program (JASP) VR Subgroup Fuel and Fire Protection Systems Committee (Navy, 1999-2009), focusing on the reduction of aircraft fuel systems vulnerabilities. Joe championed and co-developed groundbreaking VR technologies for aircraft, with special recognition in self-healing polymer plastics and passive fire extinguishing system. His efforts assisted with the development of these technologies, with the end result of incorporation of the Firetrace passive fire suppression system used today on the V-22 aircraft.

- Navy Co-Chair for the JASP VR Subgroup (Navy, 2009-2013), focusing on VR technologies for aircraft systems.

- Navy Deputy Test Director for the Joint Live Fire Program (Navy, 2009-2013), responsible for the evaluation of vulnerabilities of Department of Defense legacy aircraft.

- Engineering Section Head for the Vulnerability Test Branch at NAWCWD China Lake (2009-2014), where he managed and led a team of highly skilled survivability-vulnerability test personnel.

Joe has brought significant contributions to the aircraft design community, the JASP, and the soldier over his career. His leadership, military experience, management skills, insight, and relentless commitment towards finding means in reducing aircraft vulnerabilities has brought real change towards protecting the soldier and saving lives.

JASP congratulates Joe on his distinguished career, thanks him for his contributions to our community, and wishes him the best in the future adventures that await him and his family.

JOHN M. VICE RECEIVES AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS (AIAA) SURVIVABILITY AWARD

On 16 January 2014, John M. Vice, President of Skyward, Ltd., was presented the biennial AIAA Survivability Award at the AIAA SciTech 2014 Forum and Exposition in National Harbor, MD. The award, given by the AIAA Survivability Technical Committee, recognizes outstanding achievement or contribution in design, analysis, implementation, and/or education of survivability in an aerospace system. Mr. Vice was recognized for his leadership and technical contributions instrumental in enhancing aircraft survivability through test and evaluation (T&E), combat data collection, and aircraft battle damage assessment and repair.

Mr. Vice, an AIAA Associate Fellow and member for more than 44 years, was instrumental in chartering, organizing, and operating the AIAA Survivability Technical Committee, and served as its secretary from 1989 to 1995. He served in the US Air Force for more than 20 years, becoming involved in nuclear and nonnuclear survivability programs during this time. After retirement from the Air Force, he served as director of the Survivability/Vulnerability Information Analysis Center for more than 7 years. Following a successful period as a survivability consultant, he co-founded and continues to serve as President of Skyward, Ltd.– a small business firm that for more than 16 years has been serving clients in system survivability analysis, vulnerability reduction, modeling and simulation, and T&E support.

Now semi-retired, Mr. Vice and his wife, June, have resided in the mountains of Columbus, NC since 2002.

SURVIAC

The Survivability/Vulnerability Information Analysis Center (SURVIAC) is the Department of Defense's (DoD's) "focal point for nonnuclear survivability/vulnerability data, information, methodologies, models and analysis relating to US and foreign aeronautical and surface systems. SURVIAC's scope covers the survivability of US systems to threat weapons as well as the effectiveness of US weapons against foreign systems. Homeland Security/Homeland Defense has most recently been added to the SURVIAC technical scope." [1]

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JCAT CORNER

by Scott Cassett, Lt Col, USAF

Major (Maj) Cory Cooper has now passed the halfway mark in his role as the deployed Joint Combat Assessment Team (JCAT) assessor at Bagram Air Field, and will be replaced by First Lieutenant (1st Lt) Phil Reinert in late March 2014. 1st Lt Reinert's background as aircraft systems engineer for the Training Aircraft Division, T-6 Texan II office will be put to good use in this deployed role. Maj Dave Garner has returned home from Kandahar Air Field, and 1st Lt Kelli Walker is now providing JCAT support there. She comes from the Materials and Manufacturing Directorate of the Air Force Research Laboratory.

A pillar of the JCAT mission, Chief Master Sergeant Rick Hoover has officially announced his retirement from the Air Force Reserve after 23 years of active duty and reserve service. Lieutenant Colonel (Lt Col) Arild Barrett performed a rapid deployment to Operation ENDURING FREEDOM, which spanned the months of August and September 2013. While also providing direct augmentation to the deployed US Air Force (USAF) JCAT assessors to assist with the busy summer "fighting season," he traveled to both USAF JCAT operating locations and the deployed Navy assessors. These side trips proved to be fruitful sources of information on current issues facing JCAT personnel in theater, which is now being used to fine tune the support provided from the Continental US JCAT personnel. Among the recurring themes were security classification conventions and JCAT report simplification. Lt Col Barrett also had the opportunity to interface with the 377nd Afghan Air Force helicopter squadron based at Kabul, commanded by Lt Col Haji Baktullah. This unit operates Mi-17 utility and Mi-35 gunship helicopters, and has come a long way in incorporating JCAT techniques into their operating procedures. ASJ

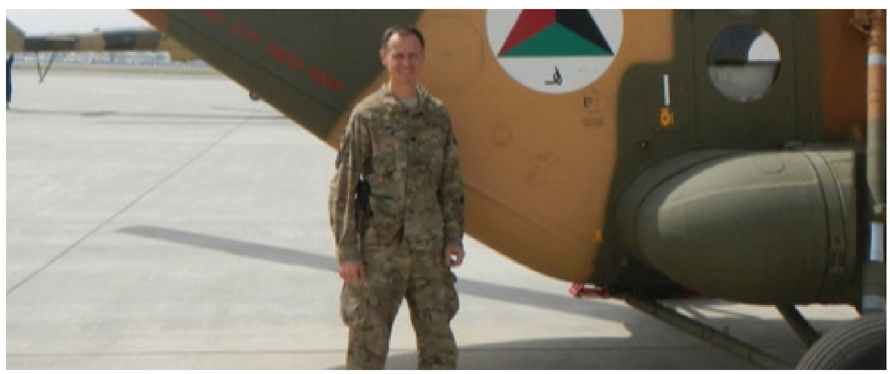

Figure 1 Lt Col Barrett at Kabul with Afghan Air Force Mi-17

COVER STORY

FIGHTER AIRCRAFT SURVIVABILITY–A PERSPECTIVE

by Mark Stewart

After almost 30 years of working in the survivability discipline, I have seen a lot of changes. Some changes were positive, others…you be the judge. I have had the privilege to work on several fighter aircraft programs, including the F-16, F-22, and the F-35. I would like to think I had at least a small part in improving the combat effectiveness of these platforms, but I have probably failed more than I have succeeded in these endeavors. Sometimes I believe I have lived my professional career to provide a list of things not to do. And, while The Fundamentals of Aircraft Combat Survivability Analysis and Design [1] still provides the foundation for the discipline, there were many things I just had to muddle through. It is with no small amount of trepidation that I offer a few words that I have discovered to be true over the course of the years. Maybe an idea or two in the writing below will provide insights on what has happened…and on what to avoid.

CHANGES IN THE PROCESS (AND THINGS THAT REMAIN)

"Back in the day"…I discovered that the "discipline" in fact seemed to have very little to do with discipline. Kill mechanisms and component vulnerabilities were anecdotal in nature, with test data only a vague recollection of events. We now use computer-aided design (CAD) techniques to create truly marvelous 3-D target models in "living color" and run analyses that take days of computer time. I was told that the first F-16 target model (created before my time) required five people and 2 years to complete—a model that contained less than 2 Mbytes of data. In contrast, the 2001 version of F-16 target model was created in 6 months, and weighs in at over 220 Mbytes; more recent F-35 models are in the 1 Gbyte category.

More complete? Yes! Prettier? Undoubtedly. Some would say, however, that the new models have gone too far; that the huge size of these models makes them much more difficult to debug and to analyze; that "who knows" what lurks in the shadows of these behemoths; that it would be better to still create target models "by hand" so we know exactly what we are analyzing. I understand these arguments, but believe that resistance to this evolution is futile. The

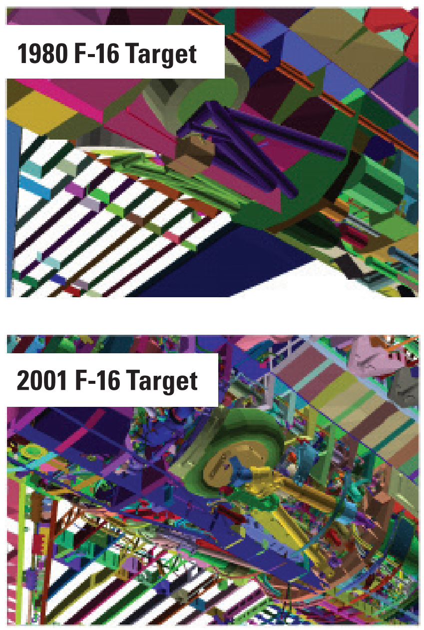

Figure 1 Comparison of Simple and CAD-based Target Models

fact remains that you cannot get an accurate representation of a shotline without accurate geometry. It is also a fact that CAD conversion is by far more efficient in creating target models than by creating them from scratch; however, CAD-based geometry has a host of issues as well, and is not the solution of the modeling process. We have discovered raised lettering on some parts, fastener holes in composite skin panels, and many other unnecessary "features" (see Figure 2). These new models sometimes have the ability to render your computer helpless when attempting to display and analyze them. There are many

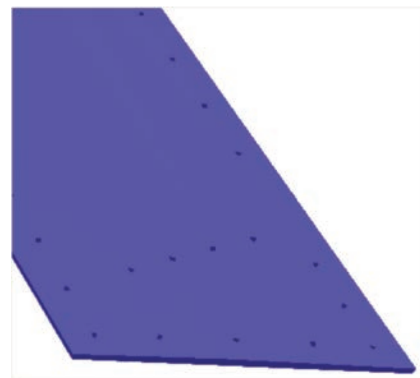

Figure 2 One Unintended Consequence of CAD-based Models: Fastener Holes in Skin Panels

more places for mistakes to hide, and many more tests to conduct and statistics to review to aid the analyst in finding issues. In my opinion, the use of CAD-based geometry is a necessary evil; we as analysts must remain vigilant in checking and analyzing the geometry. We must always remember that there are no perfect target models (or perfect analyses for that matter), and we can only make them as good as our budgets allow.

In the distant past, analyses were done "by hand" using scale drawings, colored pencils, and a planimeter. This led to few threat types being analyzed…we usually stayed with a single high explosive incendiary (HE-I) threat because "that's the one other people have used," and "we need to be able to compare one airplane to another." Now we can analyze many different threats, all with computerized models. More analysis generally leads to better insight. It also increases the overhead and complexity of the analysis, and the possibility of errors increases as well. It is easy to fall into the trap of just generating more numbers and missing the big picture—analyses are done to enhance survivability; we can't let the mechanics of conducting the analysis prevent that.

In the past, a scarcity of usable test data was forcing analysts to rely on the adage "that's the way we've always done it;" however, the Live Fire Law (Title 10) changed that. Title 10 has provided a means of actually challenging analysis assumptions and investigating uncertainties, at least to a limited degree. It has forced some "discipline" into the discipline. Title 10 continues to force the analysts to consider why an assumption was made, and to be able to defend that assumption.

COMMON MISCONCEPTIONS

Some ideas must continually be challenged. I present the items below as misconceptions that have persisted throughout my tenure in the vulnerability analysis discipline:

"Misconception: Aircraft avoid being hit so well that vulnerability reduction is not necessary."

At least for the fighter aircraft I have been involved with, there is a tendency to focus on susceptibility reduction, almost to the exclusion of vulnerability reduction. Common sense dictates that if there are methods that reduce susceptibility, these methods must be considered first. The problem arises when almost every feature is onboard solely to prevent being hit, and our "invisibility" is used as an excuse to ignore vulnerability. Hits happen. If the air vehicle is used in scenarios and/or missions other than those specifically analyzed one can expect that, as they say concerning gas mileage, "your results may vary." The same common sense that espouses to work the susceptibility issue also dictates that risk is further reduced by considering vulnerability reduction as well. A diversified "portfolio" reduces risk.

"Misconception: Aircraft are always killed if hit."

I call this the "Airwolf Syndrome." If you are too young to understand the reference, I'll explain. On this popular TV show about a high-tech helicopter, when the bad guys were encountered by a good-guy missile, it always resulted in a huge explosion, resulting in complete annihilation of the bad guys. Apparently, many of our leaders watched Airwolf as children, and have a deeply ingrained belief that vulnerability reduction is an exercise in folly. Another benefit of Title 10 is that we have been able to make video records showing that total annihilation is not the usual outcome.

Figure 3 F-35 Live Fire Testing at China Lake

"Misconception: Vulnerability analysis is unnecessary if safety analysis is accomplished."

To those unfamiliar with the nuances of vulnerability assessments, it would seem that safety-related features and vulnerability reduction features would always work in concert. In reality, safety features may do nothing to improve vulnerability, and *vice versa*. Many times, a combat-initiated kill mechanism would never be considered in a standard safety assessment because it would require more than one independent "failure." A prime example is dry bay fire; if the area in question is outside a fire zone, safety folks will say it would take a leak plus a spark to initiate a fire (two independent failures) that would not be likely to happen at the same time. In a vulnerability assessment, however, most threats excel at causing leaks and sparks simultaneously.

Sometimes the stars will align and the two disciplines advocate the same feature, but many times a vulnerability reduction feature adds complexity to the subsystem it is protecting, and complexity translates into reduced reliability and/or safety. The realms of peacetime safety and combat vulnerability do overlap, but there are certainly areas in both disciplines that are unique.

"Misconception: Vulnerability reduction techniques are either costly or heavy."

It is certainly true that some vulnerability reduction features fall into one of these categories. On high performance combat aircraft, "armor" is always a four-letter word. Other techniques must be carefully considered before implementation to avoid excessive costs and weight. Retrofit is definitely to be avoided; adding a vulnerability reduction technique after production has begun is very, very inefficient and costly; however, there are several vulnerability reduction features that can result in significant improvements without the excessive penalties. A great example would be to shutoff/isolate flammable fluids as opposed to fire suppression. Emphasize the elegant solutions over brute force; these have a better chance of implementation.

Figure 4 Full-Up System Level (FUSL) F-35 Tests at China Lake

"Misconception: Live fire testing is an unnecessary fact of life."

We must continue to demonstrate why this statement is false. The fact remains that there are many assumptions we still have to make in our analyses, and as the emphasis on modeling and simulation continues to gain momentum, uncertainties and assumptions must be addressed through testing. One should remember that many times a "live fire test" may have nothing to do with shooting something. Controlled damage tests are generally less expensive and thus conducive to running more repetitions and cases; they will continue to play a significant role in gaining insight into complex subsystems.

"Misconception: It's too early to conduct vulnerability analyses."

You don't need a huge, complex target model to conduct a vulnerability analysis. Many insights can be gained from simple qualitative analyses, early in the design process. And, given a little time, even simple target models with little or no subsystem definition can be used to investigate some of the major issues. We tend to rely solely on high-dollar COVART (Computation of Vulnerable Area Tool) analyses, and have almost forgotten that we can still provide valuable insight by using the basic vulnerability equations. After all, it's not rocket science!

MUST HAVES

In addition to the misconceptions mentioned above, time and testing have shown that a few things are necessary to achieve decent vulnerability analysis results.

Integrated Vulnerability Assessment Team

Designers require constant care and feeding. Conducting a vulnerability analysis from afar is not optimal and will undoubtedly result in misunderstandings and errors in the analysis. This is due to the fact that engineers tend to be overly optimistic about their designs and sometimes cannot make the mental leap to consider there are vulnerabilities inherent in their systems. You, as the analyst, must ask questions, understand the answer given, and then ask it again at least two other times before you crack through the shell and reveal the truth. This is just the way people are; and it is very difficult to make these mental breakthroughs *via* phone calls, email messages, or video conferences. Another issue that I have found to be absolutely true…you cannot force a designer to fix their design if they do not want to. It takes time to foster a relationship of trust; designers need to develop not only an understanding of the issue, but they must believe that the feature is reasonable and necessary.

Infrastructure: Computer Capability

It is almost impossible to conduct a good analysis using a full-up, CAD-based target model with inadequate computational resources. To be able to check the analysis results and rerun several iterations, you must be able to turn around your vulnerability assessments within a week (after all inputs are generated). If it takes a month to complete the assessment, the tendency is not to look too closely at the results because you "can't stand the answer" if you find a significant mistake. Trust me… the mistakes are there; you just have not found them yet.

Tools: FASTGEN (FAST Shotline Generator) and COVART are Only a Fraction of the Tools Required

Without utility codes and post-processors, it is really difficult to conduct a viable assessment. We have developed literally dozens of utility programs over the years to help us improve our efficiency and reduce systemic errors. Without this infrastructure, you tend to spend all your spare time doing simple corrections to the geometry, and have to neglect other aspects of the analysis. These types of tools tend to maximize your budget dollars while improving the quality of the analysis.

Time: More Time = Lower Uncertainty

Many times I see an analysis end with a set of vulnerable areas"…and the answer is 5…any questions?" There are too many ways to introduce errors in these assessments to assume the first time you run it, it is right. And, without a meaningful benchmark, vulnerable areas are just a bunch of numbers; therefore, you need time to run excursions to make sure that the expected outcomes do occur when you make a change. You have to be able to compare and contrast your analysis with a previous analysis or the analysis of another aircraft to have any credibility or meaning.

Options: Mature Vulnerability Reduction Features

Immature vulnerability reduction concepts are killers. The System Development & Demonstration phase of a program is not the time to be developing a new potential feature. Anything that is not a tried and true vulnerability reduction candidate must be tested very early in the program; otherwise, there is little hope of implementation.

Testing: An Integrated Live Fire Test Plan – Addresses Uncertainties in Analysis

Finally, testing and analysis are symbiotic functions. Live fire testing provides the data to spot-check the analysis and to address uncertainties or issues. The analysis shows which areas, components, or subsystems need to be tested. And, we all need to be willing and able to share the results of our tests with other programs; to do otherwise would just be a waste.

SUMMARY

Some things have definitely changed over the years, but the need to remain vigilant when dealing with designers, to challenge the assumptions in your analysis and continue checking your inputs and comparing your results with previous analyses are all still important to improve the state of the art in vulnerability assessments. It still comes down to the analyst conducting the analysis, and this fact will never change. ASJ

References

[1] Robert E. Ball. The Fundamentals of Aircraft Combat Survivability Analysis and Design (Reston: American Institute of Aeronautics and Astronautics, Inc., 2003).

INTEGRATED AIRCRAFT AND CREW PROTECTION

by Mark Robeson

The US Army's Aviation Development Directorate (ADD)–Aviation Applied Technology Directorate (AATD) executed a project to evaluate and select technology for enhanced aircraft and crew/occupant protection, improved durability, and reduced environmental vulnerability in an integrated, platform-level prototype without impacting mission performance. In the project, entitled Integrated Aircraft and Crew Protection (IACP), threats to aircraft and occupants were defined, vulnerability to those threats was quantified, and technologies addressing those threats were identified. Prototypes were defined based on production Army rotorcraft with mature technologies added as independent point solutions. Less mature technology solutions were also identified, traded at the system level, and integrated into weight-constrained, system-level prototypes. The differences between these production platforms, the prototypes with independent point solutions, and the prototypes with integrated solutions were quantified in terms of project metrics. In the three cases considered in IACP, the integrated approach yielded significantly larger improvements than did the approach using independent solutions.

INTRODUCTION

High operational tempo requirements, asymmetric threats, and harsh operating environments all impact the operational availability of Army rotary wing aviation assets. Current qualification methodology is intolerant of any form of structural damage, and while this approach provides high assurance of structural integrity and mission reliability, it negatively impacts operational availability. In addition, crew, passengers, and aviation platforms are vulnerable to conventional threats, such as small arms fire. Hard landings and crash landings cause damage sufficient to make the platform unavailable for operations. Aircraft damaged in flight cannot reduce loads to damaged areas to limit propagation, and rotor systems cannot adapt to deal with partial blade loss or to effectively manage energy during an unpowered descent.

Figure 1 Total Survivability Chain

The addition of operational availability to the traditional survivability components of susceptibility and vulnerability has resulted in a paradigm called total survivability (see Figure 1). Technology is available to increase the durability of the platform, and to reduce the vulnerability of the crew and passengers to hostile threats and crash injury or death. These vulnerability reduction technologies can reside in the airframe structures, rotor system, vehicle management system, and vehicle subsystems for overall system benefits, which include increased operational availability. These technologies enable a platform to avoid/absorb damage, avoid destruction, and return to service. An increase in total survivability

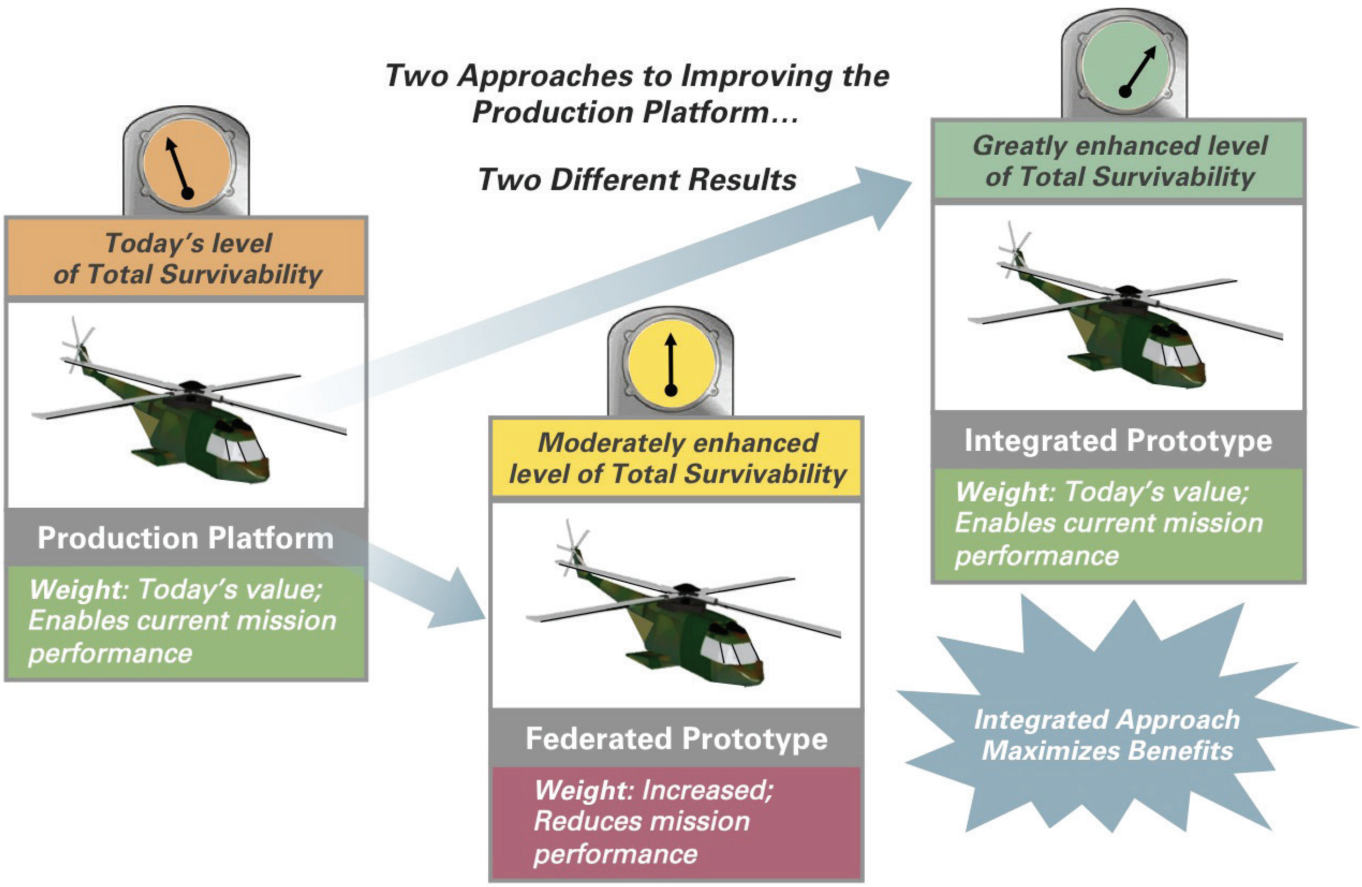

Figure 2 IACP Approaches

means improved aircraft/crew protection and a more operationally available aircraft.

APPROACH

To explore the benefits of increased total survivability afforded by vulnerability reduction technologies, the US Army's ADD–AATD executed a project entitled IACP. [1,2] Through multiple contracts with industry, IACP focused on technology evaluation and selection targeting future demonstration of enhanced aircraft and crew/occupant protection, improved battlefield durability, and reduced environmental vulnerability in an integrated, platform-level prototype without a deleterious effect on mission performance. For the technology spectrum under consideration in IACP, the constraint on mission performance was effectively a prohibition on increasing platform weight. A key objective of IACP was to illustrate the contrast in how an integrated, system-level approach provides greater benefits than a federated (assembling independent point solutions) approach to using technology to enhance platform total survivability (see Figure 2).

The federated approach considered in IACP consists of combining independent, typically mature, technology upgrades to a platform. This maturity is typically reflected by technology readiness levels (TRLs) of 8 or 9. [3] This federated approach is often seen in upgrades to Department of Defense aircraft as executed by program management offices in response to perceived urgent needs, and often results in increased platform weight.

On the other hand, as explored in IACP, the integrated approach consists of fully blending, both with each other and at the system level, technology upgrades into a platform. To support this broad integration and offer greater potential benefits, less mature (typically TRL 4-7) technologies were considered in the integrated approach of IACP.

In executing IACP, a wide spectrum of threats to platforms and occupants were defined, vulnerability to those threats was quantified, and technologies to counter or address those threats were identified. Federated prototypes were defined based on current production Army rotorcraft with mature (TRL 8-9) technologies added on as independent point solutions. Less mature (TRL 4-7) technology solutions were identified, traded at the system level, and fully integrated into weight-constrained, system-level integrated prototypes based on current production Army rotorcraft. The differences between these production platforms, the federated prototypes, and the integrated prototypes were quantified in terms of project metrics related to total survivability.

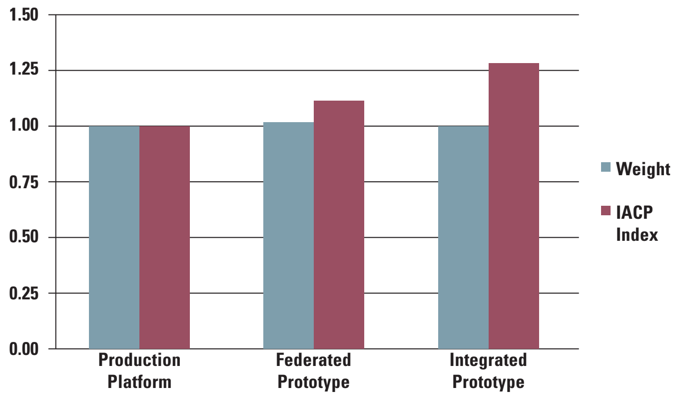

Figure 3 Case 1 Results

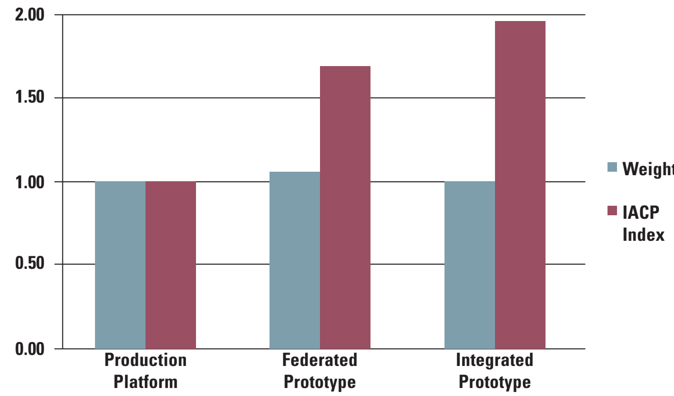

Figure 4 Case 2 Results

Three cases, corresponding to different current production Army rotorcraft (unspecified herein) of different mission types and subject to different threats, were considered in IACP.

RESULTS

Case 1

The IACP metrics initially used for Case 1 included weight, a system hardening index, a crashworthiness index, and operational availability. The system hardening index was a function of probability of kill given a hit for various threats, such as small arms fire, the crashworthiness index was based on the Full Spectrum Crashworthiness Criteria [4], and operational availability represented a percentage of time that the aircraft was available for mission use. As part of the technology trade study and benefits quantification process, a composite IACP Index was defined as follows:

IACP Index = (Normalized System Hardening Index)
* (Normalized Crashworthiness Index)
* (Normalized Operational Availability)

Weight and the composite IACP Index were then used as the metrics for Case 1.

For the federated prototype, mature technologies incorporated were transparent canopy armor, crashworthy crew seats, a cockpit airbag system, composite airframe structure, and structural usage monitoring technology.

For the integrated prototype, extensive trade studies were carried out to determine the most effective solution integrating TRL 4-7 technologies, both with each other and into the platform at a system level. The goal in the trade studies was maximizing the IACP index without impacting platform mission performance through a weight increase. The resultant integrated technology solution suite included advanced transparent armor, a comprehensive crash predictive and subsystem control system, an inflatable restraint system, crashworthy energy-absorbing crew seats, composite drive shafts, and extensive composite fuselage structure. These TRL 4-7 technologies provided the opportunity for a more thorough integration as compared to corresponding technologies used in the federated prototype.

The weight and IACP Index values for the Case 1 federated prototype and integrated prototype were determined and compared with corresponding values for the Case 1 production platform (see Figure 3). While the federated prototype provided an 11% improvement in IACP Index accompanied by a slight weight increase, the integrated approach yielded a 28% improvement with no weight penalty (a slight weight decrease, actually).

Case 2

The IACP metrics for Case 2 were the same as those used for Case 1—weight and the composite IACP Index.

Mature technologies incorporated for the Case 2 federated prototype were transparent canopy armor, crashworthy crew and troop seats, a cockpit airbag system, high-energy crashworthy landing gear, composite airframe structure, structural usage monitoring technology, rotor blade erosion control technology, an advanced drive lubrication system, and ballistically hardened swashplate actuators.

As before, extensive technology trade studies were carried out to define an integrated prototype with the most effective solution, integrating TRL 4-7 technologies both with each other and into the platform at a system level. The resultant technology solution suite for Case 2 included advanced transparent armor, crashworthy crew seats, crashworthy troop seats, fuel tank reconfiguration, advanced composite structure, composite drive shafts, ballistically hardened swashplate actuators, rotor blade erosion control technology, rotor track & balance/vibration technology, and advanced flight

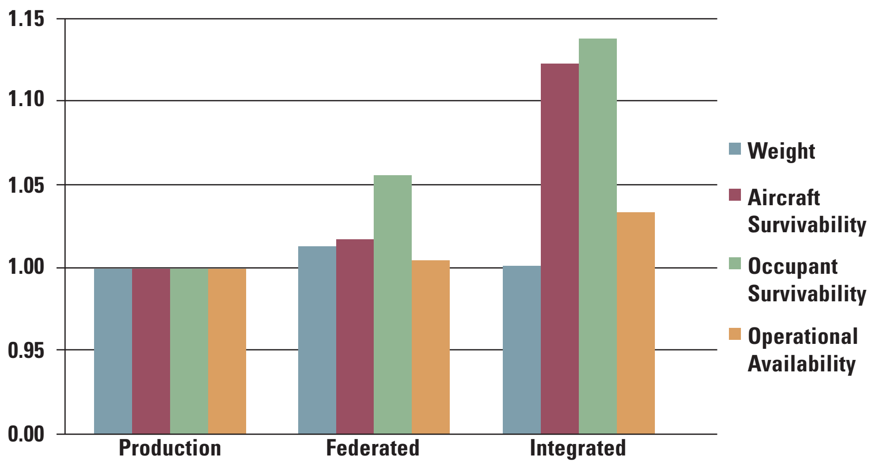

Figure 5 Case 3 Results

controls. These technologies also offered increased opportunity for integration as compared to the corresponding mature technologies used in the federated prototype.

The weight and IACP Index values for the Case 2 federated prototype and integrated prototype were calculated and compared with corresponding values for the Case 2 production platform (see Figure 4). In this case, the federated prototype provided a 68% improvement in IACP Index at a weight penalty of about 5%, but the integrated approach yielded a 95% improvement with no weight penalty (as before, a slight weight decrease, actually).

Case 3

The IACP metrics for Case 3 included weight, aircraft survivability, occupant survivability, and operational availability.

For the Case 3 federated prototype, the mature technologies incorporated were upgraded rotor damper technology, fly-by-wire flight controls, composite fuselage skins, a dry bay fire extinguishing system, a cabin ballistic armor system, and a cockpit airbag system.

As was done in the previous cases, the integrated prototype was defined through extensive trade studies carried out to determine the most effective solution, integrating TRL 4-7 technologies, both with each other and into the platform at a system level. The Case 3 integrated technology solution suite included extensive composite fuselage structure, vibration suppression, structural health sensors, advanced flight controls, an external airbag system, fuel tank reconfiguration, ullage inerting technology, rotor blade erosion control technology, and advanced component manufacturing techniques, in addition to a few of the mature technologies that were used in the federated prototype. As before, the TRL 4-7 technologies offered increased opportunity for integration as compared to the corresponding mature technologies used in the federated prototype.

The weight, aircraft survivability, occupant survivability, and operational availability metric values for the Case 3 federated prototype and integrated prototype were determined and compared with corresponding values for the production platform (see Figure 5). While the federated prototype provided 2%, 6%, and 1% improvements in aircraft survivability, occupant survivability, and operational availability, respectively, the integrated prototype yielded corresponding improvements of 12%, 14%, and 3% with essentially no weight penalty.

CONCLUSIONS

In IACP, technology was evaluated and selected for enhanced aircraft and crew/occupant protection, improved durability, and reduced environmental vulnerability in an integrated, platform-level prototype without impacting performance through increased weight. Threats were defined, vulnerabilities quantified, and countering technologies identified. Federated prototypes were defined based on production rotorcraft with mature technologies added as independent point solutions. Less mature technology solutions were also identified, traded at the system level, and integrated into weight-constrained, system-level integrated prototypes. The differences between these production platforms, the federated prototypes, and the integrated prototypes were quantified in terms of metrics. Three cases were investigated to show that the integrated approach yielded significantly larger improvements than did the federated approach, in terms of metrics based on crashworthiness, system hardening, aircraft survivability, occupant survivability, and operational availability. The cases corresponded to aircraft of different mission types, so the quantified improvements could not be compared on a technology-by-technology basis.

The compelling total survivability benefits yielded by the integrated approach have led to this approach being implemented in multiple, ongoing ADD–AATD technology development efforts. [5,6] The fully integrated approach offers tremendous benefits to technology developers, Department of Defense Program Management Offices, and ultimately the soldier.

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EXCELLENCE IN SURVIVABILITY
DONNA EGNER

by Barry Vincent and Kevin Crosthwaite

There has been a series of commercials for BASF, claiming we do not build the systems you use, we make them better. Over the years, the Survivability/Vulnerability Information Analysis Center (SURVIAC) has had a similar mission—not to build platforms, but to make them survive better. Through those efforts, several platforms have been made more survivable. The one key person in that success has been Donna Egner. Since the beginning of SURVIAC and even before that, she has been capturing key data, lessons learned, and researching reports to provide quick response to inquiries from across the Department of Defense (DoD), each of the Services, and throughout industry.

Donna has been with SURVIAC since before it started, working with its Combat Data Incident Center predecessor. She has over 35 years of professional experience in scientific and technical library management, data collection, data base management, expansion and support, and technical and bibliographic research support in the areas of survivability and vulnerability for the community. Donna has served as the human in the loop, reviewing and accessing STI data for the community. She aids SURVIAC customers in defining and satisfying data requirements from within SURVIAC resources or beyond. She is proficient in Defense Technical Information Center (DTIC) web-based tools, such as DOAC, DTIC online access control, DoD techipedia, and DoD techspace. She has enabled all these tools and resources to be at the disposal of the survivability community.

Donna started her involvement in SURVIAC, capturing the critical combat damage data for helicopters and fixed wing aircraft from Vietnam. She has continued working closely over the years, collecting combat data from various conflicts and even today serving as the liaison between SURVIAC, Joint Combat Assessment Team, and Aviation Shoot Down Assessment Team to secure current data from Operation ENDURING FREEDOM and Operation IRAQI FREEDOM. Donna also has served as the face of this critical data for the rest of the acquisition and test communities to ensure that this data is accessed and employed in new designs of more survivable future systems. Her experience and insight have helped to refine the data collection process, and have made the data and key lessons learned useful and accessible to the next generation.

Over the years, a huge number of good people have been associated with SURVIAC's success. Contracting Officer's Representatives include Gary Streets, Jim Folck, Ray Flores, Ralph Lauzze, Marty Lantz, and Peggy Wagner. Directors include Aulay Carlson, John Vice, Kevin Crosthwaite, and Barry Vincent. JASP leaders include Dale Atkinson, LTC Jim Sebolka, John Morrow, Dave Hall, LTC Schwartz, Hugh Griffis, and Dennis Lindell. Joint Technical Coordinating Group for Munitions Effectiveness leaders include John Blumquist, Art LaGrange, Erwin Atzinger, and Bryan Paris. Director, Operational Test and Evaluation leaders include Jim O'Bryon, Tom Julian, Tracy Shepherd, and Rick Seymour. All of these people contributed greatly to survivability and all of them have relied on Donna Egner to provide them timely, accurate data. She has worked effectively with this wide range of personalities and demands. She has humbly and energetically made each of these leaders' missions her own. But, she has not just responded to leaders in the field, but continually worked conscientiously with all requesters from industry, academia, and for the sergeant in the foxhole who were united by the simple characteristic that they had a need for survivability data. She would work closely with them all to understand their requirement, often enlightening them to the fuller dimensions of their needs, and then researching and providing on-target, on-time answers to their needs.

With no less dedication, Donna has served as her church' s pianist, Girl Scout leader, mother to Katy, and caregiver for her mother. Her character, values, and industry have always been an example to all. Booz Allen Hamilton recognized her with their Values in Practice award for her service in the community beyond the workplace. She has been a true friend to many, while being a key asset to the survivability community. While Donna has not produced a weapon platform by her actions and diligence, she has made several more survivable. She is very deserving of this recognition for her excellence in survivability. It is with great pleasure that JASP honors Donna Egner for her Excellence in Survivability contributions to NAVAIR, the survivability community, and the soldier.

NEWS NOTES

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Since it's inception in 1984, Booz Allen Hamilton has operated SURVIAC. The Information Analysis Center (IAC) has been part of the Defense Technical Information Center, but as of 9 April 2014, SURVIAC—along with five other IACs—will now operate under the Defense Systems Information Analysis Center (DSIAC). [2]

The move to DSIAC includes two distinct contracts:

- **Basic Core Operation**—Awarded to the SURVICE Engineering Company
- **Multiple Award Contract**—Collection of prime contractors expected to be awarded between now and the summer of 2014

To stay up to date on the progression of SURVIAC and DSIAC, visit *http://www.bahdayton.com/surviac/* or *http://iac.dtic.mil.* ASJ

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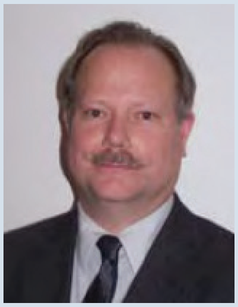
EXCELLENCE IN SURVIVABILITY
DAVE LEGG

by Torg Anderson

The Joint Aircraft Survivability Program (JASP) takes great pleasure in recognizing Dave Legg for Excellence in Survivability. Dave has most recently been appointed as the Fixed Wing Aircraft Branch Head in the Combat Survivability Division (AIR-4.1.8) in the Systems Engineering Department, Naval Air Systems Command (NAVAIR), where he heads analytical and test organizations that develop survivability requirements for new fixed wing platforms and work on survivability improvements for aircraft currently in the fleet.



Dave's most notable achievement has been to lead the survivability efforts in the P-8A Poseidon program to complete the live fire test and evaluation (LFT&E) and initial operational test and evaluation in the first half of 2013 in anticipation of a full rate production decision in October 2013. Survivability enhancements to the basic platform were thoughtfully considered in light of mission requirements, potential threats, and operational tactics; they include an extensive suite of dry bay fire suppression systems that protect the fuel tanks. This is the first production aircraft to incorporate such comprehensive fuel system protection, and the fact that it successfully remained in the design to production can be ascribed to Dave's vision and persistence.

Dave was assigned as the Navy's survivability lead for the Multi-mission Maritime Aircraft (MMA) program at its inception in 2001. Rather than accepting a position to evaluate the capabilities of the platform against survivability requirements and ensuring the Director of Operational Test and Evaluation was provided the necessary assessment documentation, Mr. Legg actively began to identify and characterize survivability improvement technologies—both susceptibility and vulnerability reduction—for what had begun as a basic airliner (the Lockheed Martin proposal was an evolutionary development of the current P-3 Orion, which began as a derivative of the Lockheed L-188 Electra airliner; the Boeing entry was based on the 737-800/900 series).

Dave directed his team of analysts to evaluate the survivability of the P-3 patrol plane that MMA was to replace, and determined the survivability improvements could be made with vulnerability reduction. He presented the findings to the Navy Requirements Office, making them aware of options for improving platform survivability. The arguments were sufficiently convincing that the final MMA vulnerability specifications would require any acceptable design to incorporate extensive dry bay fire protection. This was the first acquisition in which survivability analysts actively guided significant vulnerability improvement requirements for the platform.

As the program proceeded, the Boeing concept was selected and designated the P-8A Poseidon. As the design matured, Dave directed a Navy and contactor integrated product team in developing the dry bay fire protection system and integrating developmental testing with a test program that assessed system performance. The majority of this testing consisted of extensive "iron bird" dry bay replica testing at the Weapons Survivability Lab (WSL) in China Lake, CA for each dry bay system incorporated in the aircraft.

As with all aircraft programs, during the development cycle, the P-8A was confronted with weight, cost, and system performance challenges, but Dave's continual management of the contractor and test efforts, and his continuous communications with program management kept the vulnerability reduction design focused on its main goals and the need for vulnerability reduction central to the P-8A program requirements. As a final evaluation of vulnerability reduction performance, Dave and his team planned for a full P-8A airframe—the S-1 structural test article—to be brought from Boeing in Seattle, WA to the WSL, where ballistic testing was completed successfully with dry bay protection systems installed.

Dave's active direction and successful management of the program, from establishing the challenging survivability requirements through successful design, to implementing and evaluating the dry bay fire protection system is an outstanding accomplishment that earned Dave recognition from both NAVAIR and the Director, Operational Test and Evaluation, LFT&E.

Dave's accomplishments culminate over 30 years of service to the survivability community, primarily in support of NAVAIR. With degrees in mathematics and mechanical engineering, he first joined NAVAIR in 1983, where after gaining experience on the V-22, FA-18C/D, F-14, A-6, Joint Stand-off Attack Weapon, and Advanced Air-to-Air Missile survivability programs, he became the lead survivability project officer for the Naval Advanced Tactical Fighter (a navalized version of the Air Force Advanced Tactical Fighter, what became the F/A-22), F/A-18E/F, AH-1T, Medium Range UAV (what became the BQM-145A), and P-7 aircraft (a follow-on design to the P-3 Orion). He went on to become the A-12 Deputy Lo-observable Team Leader during that program's development efforts. Subsequent to that program, Dave became an operations analyst, performing and directing cost and operational effectiveness analyses of strike aircraft, in general.

Dave worked for a period at the SURVICE Engineering Company, where he was a survivability analyst, developing Navy air combat survivability research and development plans and helping to produce a tri-Service survivability handbook. Before returning to NAVAIR, Dave went on at SURVICE to become the live fire team leader at SURVICE's Army Test and Evaluation Command Army Evaluation Center contract site, where he supported survivability efforts for a wide range of platforms, including several ground systems (M1A2 Abrams, Bradley Fighting Vehicle and M270A rocket launcher) and helicopters (the UH-60L Plus, RAH-66, CH-47D Improved Cargo Helicopter, and AH-64 Longbow Apache). Dave returned to NAVAIR in 2000.

Dave and his wife, Mary Jo, live in Hollywood, Maryland. They have a son serving in the U.S. Army and a daughter who is a graduate student at Widener University.

It is with great pleasure that JASP honors David Legg for his Excellence in Survivability contributions to NAVAIR, the survivability community, and the soldier.

INTEGRATED AIRCRAFT AND CREW PROTECTION

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ACKNOWLEDGEMENTS

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NDIA LIVE FIRE TEST AND EVALUATION (LFT&E) WORKSHOP

by James O'Bryon

Washington, DC was the site of the recent NDIA LFT&E Workshop, an event held every 2 years and sponsored by the Test and Evaluation Division of the National Defense Industrial Association (NDIA). This workshop was the eighth in a series of live fire workshops dating back to the kick-off event hosted at the Lawrence Livermore National Laboratory in 1988. Due to the nature of the topics, this workshop was again held at the Secret/US Only level.

Attendance at these workshops has varied over the years, from more than 300 to the 65 participants in this recent workshop—the smallest to date; although every speaker listed on the agenda did present. The reduced attendance was primarily due to current government restrictions on conference participation and travel, as well as limited budgets. The workshop was hosted at the corporate facilities of Alion Science and Technology, with participation coming 55% from government and 45% from the corporate and nonprofit communities.

WORKSHOP KEYNOTE

Mr. Richard Sayre, Director, Operational Test and Evaluation's (DOT&E's) Deputy Director for Live Fire Testing, provided the keynote address. His presentation focused on recent advances made in addressing combat casualties in military platforms, primarily ground combat vehicles. Since attention to reducing combat casualties is the primary focus of the LFT&E legislation, Mr. Sayre's presentation set the tone for the rest of the workshop. It is widely known that blast injuries, primarily from improvised explosive devices, have been a primary source of injury in recent combat operations; Hence, his presentation was primarily devoted to describing progress that has been made in measuring and mitigating blast effects. He described efforts made to increase the realism of anthropomorphic hybrid manikins, and described significant steps that have been taken to improve the testing and resultant design of helmets, body armor, and vehicle design.

PRESENTATION OF THE ARTHUR STEIN AWARD

The workshop provided an opportunity to present the Arthur Stein Award in recognition of a lifetime achievement in support of LFT&E. Dr. James Walbert, this year's recipient, is currently an adjunct staff member of the Institute for Defense Analyses. He has 40 years of experience as an interior and exterior ballistician, a vulnerability/lethality tester and analyst, a materials engineer, an author, and an instructor.

VULNERABILITY ASSESSMENT METHODOLOGY

Two technical presentations addressed methodologies to assess platform combat capability after an engagement. Dr. Paul Deitz described how the process of ballistic live fire can be divided into three separable and sequential pieces: component damage, platform capability, and platform utility. With the advent of task-list formalism (both joint and Service-based), utility can be related to the ability of platforms to perform specific tasks to explicit standards and conditions in missions. Keeping the three analytical elements separate provides clarity to system assessments and extends the utility of generated data to new applications.

Dr. James Walbert discussed the complexities of performing ballistic test and evaluation on dynamic (moving) systems. Dynamic ballistic testing presents new challenges for the vulnerability analyst due to unknown conditions after the first of multiple impacts. Not only must subsequent initial conditions be inferred, but so must the effects of cumulative damage. In the case of manikins, deciding when the greatest injury occurs (first impact, subsequent impacts, or cumulative effect) can be virtually impossible.

ASSESSMENT OF OPERATION ENDURING FREEDOM/IRAQI FREEDOM HELICOPTER COMBAT DATA ON LFT&E METHODOLOGY

Presentations were made by Mr. James Rhoads (IDA) and Dr. Mark Couch (IDA) on combat data gathered on helicopters operating in Iraq and Afghanistan: what caused them to be brought down, resultant losses, and lessons learned. Dr. Couch made a presentation on methods to mitigate casualties resulting from single and multi-hit attacks on OH-58F helicopters in theater. Dr. Vince Volpe (IDA) presented a summary of the LFT&E of the AH-64E, including insights and surprises from this test program.

SURVIVABILITY/ VULNERABILITY INFORMATION ANALYSIS CENTER (SURVIAC) MOVES TO DSIAC

SURVIAC has served the LFT&E community very well over several decades. Recently, the Office of the Secretary of Defense decided to consolidate the nearly two dozen Information Analysis Centers (IACs) into three larger IACs. Mr. Greg Thompson (SURVICE Engineering) announced that SURVICE Engineering had won the contract this past month to operate the Defense Systems IAC (DSIAC). SURVICE Engineering will partner with Quanterion, GTRI, Johns Hopkins Whiting School of Engineering, and TRI (Austin) to provide the services that SURVIAC historically has provided. DSIAC will function with SURVIAC as an embedded element. This vital resource—which includes databases of combat incidents, combat injury information, technical reports relating to weapons lethality, target vulnerability, and vulnerability and lethality methodologies—will continue to provide services to the government and private sectors. In particular, DSIAC will provide quick turnaround research (up to 4 hours) at no charge to government entities and the private sector in support of government contracts. Specialized expertise and analysis support beyond the basic 4 hours are also available through DSIAC under discrete, independently funded core analysis tasks (CATs).

APPLYING DESIGN OF EXPERIMENTS (DOEs) IN LFT&E

Mr. Scott Wacker, Eglin AFB, described how his team was able to apply a DOE approach to the planning of LFT&E for the KC-46 tanker. The resulting approach enables an efficient test program that will maximize the information obtained from a limited number of test shots.

VISUALIZING LIVE FIRE TARGETS

Historically, one of the challenges to many LFT&E programs has been the time-consuming manipulation of Computer Aided Design, Computer Assisted Manufacture target descriptions to support shot selection and interpretation of results. Mr. Lee Butler (Army Research Laboratory [ARL]) described a recently developed analytical tool, "An Open Source GPU-Accelerated Vulnerability/ Lethality Analysis Framework," that he and others at the ARL have developed and exercised to enable near real-time visualization of solid-geometry descriptions of targets of interest and shotlines. It is fully interactive, is color-coded to enable better visualization of results, can be run on a laptop computer, and responds quickly.

SYNOPSIS AND RECAP PANEL

A synopsis panel was assembled to provide comment from an air, land, and sea perspective. The panel was made up of Mr. Peter Filkins (IDA), Mr. John Haas (Skyward, Ltd), Mr. Richard Sayre (DDOT&E/LFT), Dr. James Walbert (IDA), and Mr. James O'Bryon (Former Chair, NDIA T&E Division).

THE BIGGEST "TAKEAWAY" FROM THE WORKSHOP

Dr. Jim Streilein, panel moderator, asked a series of questions of each of the five panel members. The first question was simply "What is your biggest takeaway from this workshop?" These are their responses:

- Mr. Richard Sayre considered the workshop to have value for professional development, and suggested that attendees communicate what was learned through trip reports and other means. He noted the benefit of inviting senior leaders to observe significant test events. Coming off of 10 years of combat, with an emphasis on personnel casualties, it will be difficult to maintain the attention of senior leaders.
- Mr. John Haas, who works primarily with the aircraft community, commented that, while there were multiple presentations addressing the vulnerability of helicopters, he was surprised at the lack of workshop involvement from the fixed wing aircraft community. Although representatives from Lockheed Martin, Northrop Grumman, SURVICE Engineering Company, and Skyward, Ltd. were in attendance, no presentations addressed the vulnerability or survivability of fixed wing aircraft,

- which comprise 35-40% of the entire Department of Defense procurement budget.
- Mr. Peter Filkins (IDA) made a similar comment regarding the lack of participation from the Navy ship community.
- Dr. James Walbert stressed the value gained from the exchange of LFT&E information across the generations attending the workshop. He summed it up by saying, "You just can't Google it!" Although our business is complex and technical, we need to be clear in our definitions and use of language.
- Mr. Jim O'Bryon expressed the importance of recent progress that has been made to assess combat casualties and support design improvements to reduce casualties. Prior to the first Crew Casualty Working Group meeting in 1988 to begin seriously addressing LFT&E user casualty issues, the only major injury source being considered was from high-velocity fragments.

The LFT&E requirement has been a forcing function to expand the user casualty assessment discipline to include consideration of injury not only from fragments and spall, but also to address injury due to blast, blunt trauma, toxic fumes, acceleration, burns, fire, directed energy, shock, and other injury mechanisms. Many of these damage mechanisms are now incorporated into the Operational Requirements-based Casualty Assessment (ORCA) model, which is being exercised to assess both the medical and operational effects of user casualties in combat scenarios.

SUGGESTIONS PROPOSED FOR IMPROVING THE PRACTICE OF LFT&E

There were a host of suggestions on how to improve LFT&E as a program and how to make the next LFT&E workshop even more productive, including the following suggestions:

- Invite senior defense personnel to observe selected LFT&E events, enabling them to more fully understand the LFT&E process and insights gained.
- To assure that test planning is as comprehensive as needed, a Defense Technical Information Center search should be required before LFT&E projects are initiated.
- Although it may seem impossible to place a value on each life saved or injury prevented, we should address the very real savings through measures that assess both the expected numbers of casualties and the dollar costs associated with such casualties.
- A misconception that needs to be corrected is that LFT&E is some sort of penalty or tax on a program manager, rather than an integral and beneficial part of the program's evolution.
- LFT&E programs need to broaden their threat assessments to include not only ballistic threats, but also the possibility of other expected conventional threats, such as incendiary, fuel-air explosives, radio frequency threats, and lasers.
- There needs to be more education about LFT&E. Defense Acquisition University courses consist of not more than a half dozen charts on this statutory program that affects more than 100 programs on oversight for LFT&E.
- It was clear from the general discussion that the LFT&E community should be involved in the development of system requirements, while not becoming a proponent at the same time.
- The operational test community should be a significant player in LFT&E to assure consistent treatment of threats, as well as an integrated approach to all aspects of survivability and operational lethality.
- The LFT&E community must be "spring-loaded" to collect in-theater combat data, enabling maximum benefit to be derived from these data. The areas to be addressed can be summarized as having preprinted data collection forms, data collection training and prior authority to operate in theater for data collection.

SUGGESTIONS FOR THE NEXT LFT&E WORKSHOP

A survey was distributed to the workshop participants and a number of actionable proposals were made:

- Include tutorials in the next LFT&E workshop.
- Add an LFT&E track and LFT&E tutorials to the NDIA Annual National T&E Conference.
- Address the current restrictions on travel and conference participation since in-person meetings are vital to discuss classified issues that permeate LFT&E.
- There is general agreement that a workshop every 2 years is optimal and should continue.

Questions regarding this workshop should be directed to James O'Bryon.

COMPUTER SIMULATION OF A RUNNING AIRCRAFT ENGINE IMPACTED BY A MISSILE WITH WARHEAD

by Sunil Sinha, Gregory Czarnecki, and Ronald Hinrichsen

In this paper, an attempt is made to analytically predict damage to a running turbofan jet engine hit by a missile. The predictive methodology is based upon developing a LS-DYNA® finite-element model of the entire engine as well as the exploding missile. The analytical simulation considers both the effect of ballistic energy as well as the pressure pulse generated as a result of detonation of the warhead in the missile. The engine model accurately captures the complex dynamic effect of transient imbalance forces and gyroscopic moments caused in a dual concentric rotor system spinning at two different speeds.

INTRODUCTION

Routine operations of commercial aircraft involve a potential for sustaining many different types of foreign object damage (FOD). Typical FOD to a jet engine component can be classified under two categories: soft-body impact and hard-body impact. Typical examples of soft-body impact include bird-strike and ice. Modern jet engine components are designed to withstand very large dynamic impact loads and survive such unexpected situations. Hard-body impacts deliver such a large dynamic load that there is risk of fan blade release. Examples of hard-body impacts include structural runway FOD and terrorist missile threats. Large wide-body military and commercial aircraft are particularly susceptible to man-portable air defense system (MANPADS) missiles during take-off and landing due to large infrared emissions, slow speed, predictable flight paths, unencrypted air traffic communications, and publicly available commercial schedules. Propulsion systems on these aircraft are the largest source of infrared energy, and as such, have a high probability of being the impact point if the missile successfully intercepts the aircraft. In this paper, we report a hypothetical scenario where a shoulder-fired missile hits a running engine in flight. We present an in-depth study of analytically predicted damage to the engine as well as the transient loads developed at the engine mount system.

The analytical simulation involves modeling the engine and the missile using correct physics of high-velocity impact and target penetration. The explosion-related traveling pressure-wave is modeled separately using blast modeling procedures. [1, 2, 3, 4] The engine's finite-element mesh includes details of the outer structure, which likely disrupts the missile trajectory and blast. For example, parts of the turbine casing that have honeycomb structure were considered in the finite-element mesh. Elastic-plastic material modeling of various engine components includes strain-rate dependent material properties as well as high-temperature characteristics especially in the turbine area. [5, 6] The current summarized report is based upon the authors' earlier detailed technical paper recently published in the AIAA Journal of Aircraft. [7] The overall project summary of this effort and contribution of various organizations were outlined in the previous issue of the Aircraft Survivability Journal. [8]

DETAILS OF THE ANALYTICAL MODEL

RHAMM Technologies, LLC developed the missile model using LS-DYNA® under guidance from the 96th Test Group and the Joint Aircraft Survivability

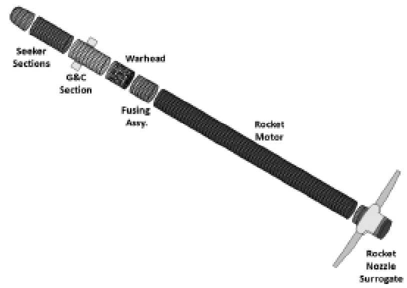

Figure 1 MANPADS Model

Program Office (JASPO). Also under guidance from the 96th Test Group and JASPO, GE Aviation developed an LS-DYNA® engine-MANPADS modeling procedure capable of producing high-fidelity predictions of damage on a large turbofan engine. GE then applied the modeling procedure to develop credible damage predictions for hypothetical missile engagement scenarios.

The MANPADS missile model includes seeker, warhead, guidance and control, and rocket motor sections (see Figure 1); and contains detailed data on section properties, exterior dimensions, joint construction, joint strength, component construction, material properties, mass properties, and rocket motor case strength. The missile model consists of 59,576 nodes, 39,725 shell elements, and 9,809 deformable solid elements. Warhead fragments are modeled with 4,032 rigid elements. Model materials include glass, phenolic, aluminum, and steel. Non-linear material models are employed where density, elastic modulus, yield stress, tangent modulus, and failure strain (to include the nonlinear stress-strain curve) are specified.

The missile warhead contains high explosive materials. When detonated, significant blast pressures and warhead fragmentation occurs. To obtain the correct fragment pattern and velocity distribution, a coupled fluid-structure interaction technique was chosen. In this technique, the explosive and surrounding air were modeled as fluids in an Eulerian domain. Warhead structures, including fragments and end caps, were modeled in the Lagrangian domain. Fragment accelerations for the first several microseconds were extracted from this analysis and combined with the fragment masses to obtain fragment force *versus* time curves. This computation-intensive coupled analysis was performed once so force curves could be generated. These curves were then economically applied within the Lagrangian model of the MANPADS model. Blast characteristics of the warhead were introduced into the model using a parametric representation developed for the conventional weapons effects code. The warhead explosive charge was mass-scaled to match peak pressure and the time of arrival of the pressure pulse as a function of range.

Figure 2 shows the model-generated peak pressure *versus* range compared with experimentally obtained data. The peak pressures shown in Figure 2 are "side-on" pressures. The comparison with the side-on pressures is shown because that is what was measured in the experiments that were performed in static arena tests. The actual application of pressure in the finite-element model does incorporate the pressure contributed from the dynamics of the blast wave. Implementing the effects of drag on fragments in the model was done using a mass damping option in LS-DYNA®.

The complete engine model included a full representation of the low pressure turbine (LPT) case, high pressure turbine (HPT) case, exhaust nozzle, exhaust cone center body, turbine stator vanes/nozzles, cowling and nacelle, forward and aft-mount system, and low pressure (LP) and high pressure (HP) rotors. In the engine model, the LP rotor rotates at roughly one-third the speed of the HP rotor. This is the first LS-DYNA® model of its kind that simulates a dual concentric rotor system with the rotors spinning at two different speeds.

Figure 3 shows two different views of the engine model. The model includes stator and rotor components typical of jet engine construction. The full-engine LS-DYNA® model consists of about 1.5 million nodes and elements, where the majority of elements are eight-noded solid brick elements. About 100,000 shell elements are used to represent stator and rotor airfoil blades and stator vanes and nozzles. Since the intention of the engine finite-element model is to study missile impact and detonation related

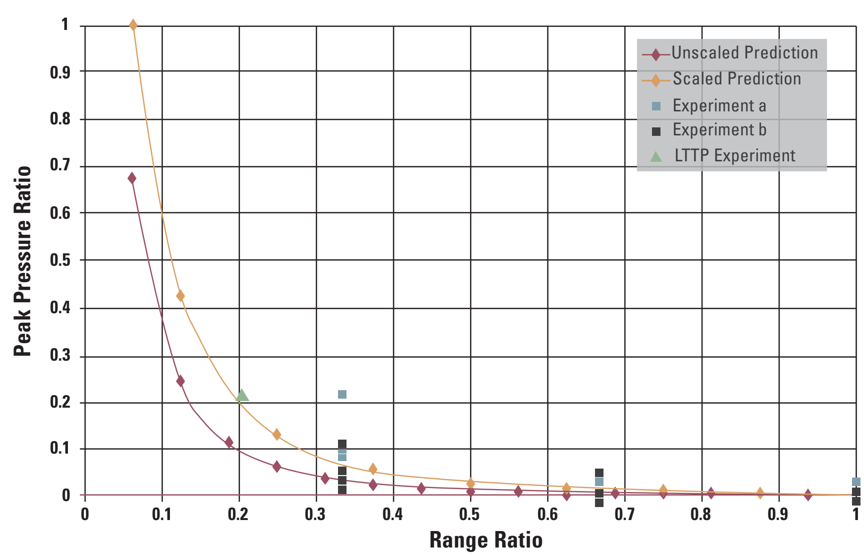

Figure 2 Model Generated Peak Pressure Compared with Test Data

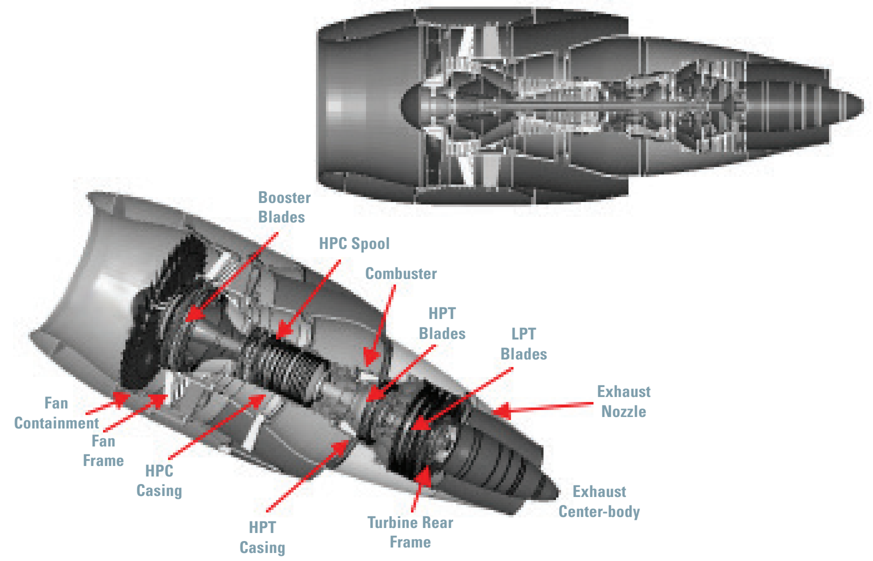

Figure 3 Two Views of the Full Engine LS-DYNA® Model

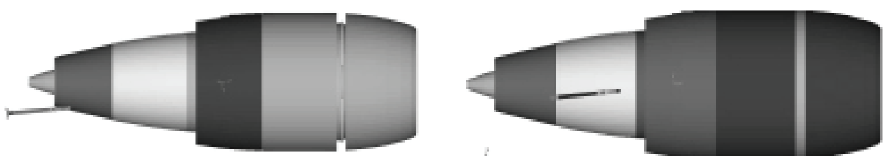

Figure 4 Missile Model Coupled with Engine Model for the Two Shotlines Orientations

damage, aft-end components of the engine were represented using an extremely refined mesh. Due to very high strain-rate involved in these simulations, strain-rate dependent properties were used.

In the engine-MANPADS analysis, two different aft-end shotlines are considered (see Figure 4). In the first shotline, the incoming missile enters the engine at the exhaust cone; in the second shotline, it goes towards the core of the engine. Note that the missile and engine are shown in the same scale. For each engine-MANPADS engagement scenario, the transient dynamic analysis continues for 15 milliseconds from the time of initial missile contact.

The main challenge concerns modeling the bearing surface interface between the rotating shaft and the outer-race bearing surface connected to the stator structure. In the jet engines, there are two types of bearings: ball bearings (can take axial loads) and roller bearings (cannot take axial loads). In LS-DYNA®, the stator side of the ball bearing is represented by a U-shape groove for the rotor side elements to be sitting inside two axial walls, preventing its axial movement. The stator side of the roller bearing is represented by a cylindrical surface, such that the rotor side elements are free to move axially. In this modeling approach, one represents the core of the engine with two concentric rotors involving the fan-LPT rotor as the inner rotor and HPC-HPT rotor as the outer rotor. The model is capable of capturing deformation in the shaft due to relative rubbing of two concentric rotating shafts. It is very important from the dynamic results accuracy point of view that individual blades on both rotors are modeled in such a way that their deformation due to rub or their clashing with any stator components is properly captured in the LS-DYNA® model. Due to typical dimensions of the parts, the disks are usually represented by eight-noded brick elements.

Initial conditions of the engine and missile are incorporated into the simulation by imposing stresses and velocities on the finite elements of rotating parts of the engine, positioning the missile model at the surface of the impact point, and giving all nodes associated with the missile their initial velocities.

Since LS-DYNA® is an explicit time integration code, there is a minimum time-step size imposed by the Courant condition of the model, which is dependent on the smallest deformable element. As many of the elements were quite small, the minimum time-step was also small (less than 1.0x10-6 seconds). To maintain solution stability over many time-steps as well as to complete the computations in a reasonable time, while capturing the majority of damage resulting from the event, the simulation duration was limited to 15 milliseconds.

RESULTS OF THE ANALYSIS

The majority of the missile-induced damage to the engine is confined in the near vicinity of the initial contact. This is true for both shotlines 1 and 2, and is also true because the duration of both of the analyses was limited to 15 milliseconds from the time of first contact.

Figure 5 shows damage predictions. In these plots, color fringe patterns highlight the areas of large plastic deformation in various engine components.

The damage shown in Figure 5 is a result of the accumulation of damage resulting from the forces imposed on the model elements from all sources. These sources include the blast pressures, impacts of fragments from the missile warhead and body, as well as impacts from engine parts contacting one another. Damage is simulated using

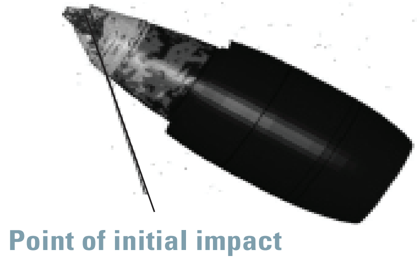

Figure 5 (a) Damage Predictions for Shotline 1

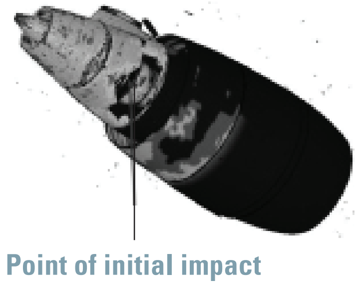

Figure 5 (b) Damage Predictions for Shotline 2

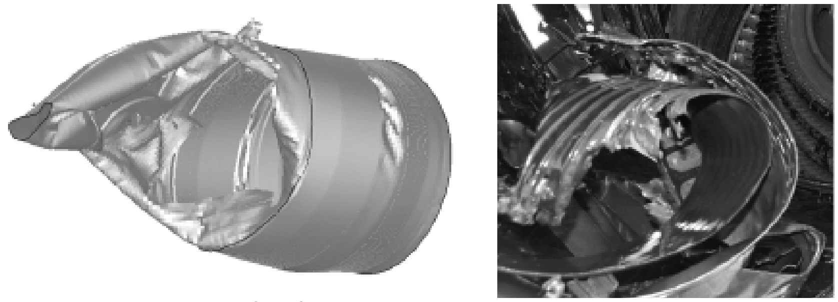

Figure 6 Damage to the Exhaust Cone Center Body

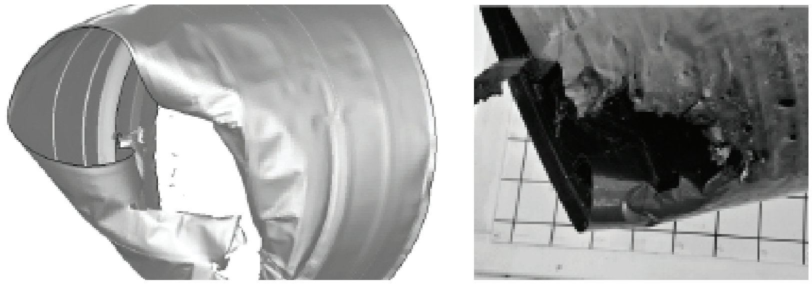

Figure 7 Damage to the Exhaust Nozzle

non-linear (and in some cases rate-dependent) material properties for all components and imposing failure criteria that have been previously determined for each of the material types used. At each time-step in the simulation, all elements are checked to determine whether their failure criterion have been reached. Failed elements are eroded out of the model before the next time-step is taken. This process continues many times with a very small time-step size using a time marching-forward algorithm until the final time is reached.

In the numerical simulation, damage caused by the pressure-blast wave can be characterized by a wide-area plastic buckling of skin in the vicinity of impact; whereas piercing and tearing of mangled metal at the hit location is the sign of direct ballistic impact by the main body of the missile. In the same way, the secondary fragmentation caused by the shrapnel is indicated by isolated holes appearing farther away from the shotline trajectory.

Analytically predicted damage results are compared with the test observations. Figures 6 and 7 show the predicted damage *versus* test damage, and illustrate the LS-DYNA® capability to credibly predict engine damage ahead of the test. Damage predictions correlate reasonably well with test results. Figure 6 shows damage to the exhaust cone center body, and Figure 7 provides a zoomed-in view highlighting damage to the exhaust nozzle.

CONCLUSION

This paper has shown it is possible to capture the full physics of missile impact and detonation on a large running commercial jet engine. The elastic-plastic failure model adequately predicts damage and correlates well with the test observations. The dynamic response of the engine—which accounts for centrifugal forces, nonlinear rub forces as well as the gyroscopic effect of the dual concentric rotors spinning at two different speeds—are computed accurately to evaluate the mount system capability under severe loading conditions. Model results are intended to support and correlate the test efforts that investigate large aircraft vulnerability to MANPADS. A proven engine-MANPADS modeling procedure can help offset the high cost of testing needed to assess operational risk within MANPADS threat environments.

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IF IT AIN'T BROKE... TRY TO MAKE IT BETTER?

by Kevin Crosthwaite

Almost 30 years ago, a new government institution was created. The Survivability/Vulnerability Information Analysis Center (SURVIAC) came to be through the active advocacy of the Joint Technical Coordinating Group on Survivability—now the Joint Aircraft Survivability Program—led by Dale Atkinson and the Joint Technical Coordinating Group for Munitions Effectiveness, led by John Blumquist. SURVIAC came into being as a government-owned, contractor-operated center of excellence, hosted at Wright-Patterson Air Force Base (WPAFB), under a contract with the Defense Technical Information Center (DTIC). Booz Allen Hamilton was the original contractor, and has been the only prime contractor to operate SURVIAC throughout that time. Contractually, SURVIAC was a follow-on to the Combat Data Incident Center and the Aircraft Survivability Model Repository.

Over the years, SURVIAC has grown in resources—libraries, data, and models—as well as in reputation from technical expertise, and in impact on the survivability community. Thousands of inquiries have been answered and resulted in satisfied customers who returned and spread the word about SURVIAC. Truly, the success of SURVIAC has been driven by the needs and support of its customers who have been willing to turn to SURVIAC with the details of their problems and requirements.

The success and growth of SURVIAC, in large part, is now led to a substantial change in the institution. SURVIAC had grown contractually beyond the core institution into a very large contract vehicle with numerous technical area tasks (TATs) with significant funding serving a wide range of customers throughout the Department of Defense (DoD). The subject matter of all of these TATs was strongly tied to the SURVIAC technical expertise of survivability, lethality, or homeland security. All of these TATs were contractually also sole source awards to the prime contractor operator of the core institution. This dependence ensured that the contractor faithfully completed all the responsibilities to enhance the core, but garnered the attention of the DoD competition advocates and small business advocates. Furthermore, budget cuts at DTIC made it imperative to reduce and consolidate the number of similar Information Analysis Centers (IACs) that had cores funded by DTIC.

The contractual solution was two part. First, the core operation part of the contract was separated from the TAT part. The Basic Core Operation (BCO) is now to be accomplished by a small business, while the TAT part is a Multiple Award Contract (MAC), where numerous primes will compete for each TAT. Second, the budget cut forced the consolidation of many of the previous legacy IACs into just three new BCOs. SURVIAC, is now joined with the Chemical Propulsion IAC, the Sensor IAC, the Weapon System Technology IAC, the Reliability IAC, and the Advanced Materials and Manufacturing Technology IAC into a new institution…the Defense Systems IAC (DSIAC). The prime contractor for the DSIAC BCO is SURVICE Engineering Company.

As many of you know, the SURVICE Engineering Company has extensive experience in survivability. They were a long time subcontractor with Booz Allen in the operation of SURVIAC since its inception. They have long been involved in survivability test, analysis, and modeling under a variety of contracts. Tom Moore, who has IAC experience as a former deputy director at CPIAC, is the new director of the DSIAC BCO. The DSIAC BCO will be headquartered at the SURVICE Engineering Company office in Belcamp, MD. The DSIAC will maintain a cell at WPAFB and retain the SURVIAC SIPRNET connection for the Joint Combat Assessment Team, CDIRS, and modeling support.

A provision of the new BCO contract is to allow for Core Analysis Tasks (CATS). CATS are essentially mini TATs, limited to under $1M and a 1-year period of performance. CATs are to be the sole source to the BCO operator and must be within the expanded scope of the DSIAC. CATs allow for some of the services the community has come to expect continue from the core institution. For larger efforts, the intention is they should become a TAT, where they will be competed under the DSIAC MAC contract. So, for whatever the size of your effort, the intention is that it will still have a home in the DTIC IAC contracts.

We realize that the DSIAC BCO has big shoes to fill. We are building our base of subject matter expertise on survivability models, analyses, libraries, and combat damage databases as well as the technical areas of the other legacy IACs, that are now part of the DSIAC. Most of you do not remember the initial faltering steps when the SURVIAC was new. With the community's support, we grew beyond our rough teething stage. Please provide the patience and support you have always rendered to the SURVIAC institution as we grow this new institution.

COMPUTER SIMULATION OF A RUNNING AIRCRAFT ENGINE IMPACTED BY A MISSILE WITH WARHEADCONTINUED

continued from page 25

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THE SURVIVABILITY TECHNICAL COMMITTEE

by Jaime Bestard

This year marks the 25-year anniversary of the Survivability Technical Committee (SURTC) of the American Institute of Aeronautics and Astronautics (AIAA). Founded in 1989 by a group of survivability experts, the SURTC was created to promote the development of survivability as a design discipline for both air and space systems. It is composed of a diverse working group of professional members from academia, industry, and government, representing the aircraft (fixed and rotary wing) and spacecraft communities. Its members provide subject matter expertise in diverse applications of the survivability discipline. The embodiment of the SURTC contributions to the discipline has been the 1985 publication by Dr. Robert E. Ball, an AIAA Fellow, of *The Fundamentals of Aircraft Combat Survivability: Analysis and Design* as part of the AIAA Education Series followed by its second editing in 2003. [1]

The SURTC is currently composed of 31 voting members [2] and five alumni. The committee is proud to include within its ranks one AIAA Fellow and 12 Associate Fellows. In 1993, the committee established the AIAA Survivability Award; since then, it has been responsible for its management, presenting a biennial award to recognize outstanding achievement or contribution in the design, analysis, implementation, and/or education of survivability in aerospace systems. In addition, since 2002, the committee has been responsible for organizing the survivability sessions at the AIAA Structures, Structural Dynamics, and Materials (SDM) Conferences, ensuring a steady survivability presence since SDM 43. Furthermore, the committee supports publications in the AIAA Aerospace America magazine, the development of specifications and handbooks, academic competitions for aircraft survivability design, and the publication of position papers on topics of interest to the community. The SURTC collaborates with the National Defense Industrial Association (NDIA) and its Combat Survivability Division, hosting its fall meeting in conjunction with the NDIA Aircraft Survivability Symposium.

Figure 1 25-year Anniversary of the Survivability Technical Committee Seal

Year	Recipient
1994	Mr. Dale B. Atkinson
1996	Dr. Robert E. Ball
1998	Mr. Nikolaos Caravasos
2000	Mr. Donald J. Wallick
2002	Mr. Michael Meyers
2004	Mr. Lawrence A. Eusanio
2006	Mr. James B. Foulk
2008	Mr. David H. Hall
2010	Mr. Walter D. Dotseth
2012	Dr. Joel E. Williamsen
2014	Mr. John M. Vice

Table 1 AIAA Survivability Award Recipients

HISTORY OF THE SURTC

The first years of the SURTC coincided with the last years of the Cold War, the technology boom of the 1990s, the widespread use of digital technologies in the aviation industry, and increased collaboration in space as exemplified by the development and assembly of the International Space Station (ISS). The 11 September 2001 terrorist attacks were a turning point for the aerospace community at large and the ensuing War on Terror revamped focus on combat survivability (particularly that of low-and-slow-flying aircraft) and civilian airliner security and safety. Meanwhile, the proliferation of space assets to support the global economy brought new challenges to the community and events during the decade highlighted existing

[1] United States Department of Defense personnel can get a free copy from the Survivability/Vulnerability Information Analysis Center by visiting *http://www.bahdayton.com/surviac/survivabilityeducation.htm*

[2] AIAA limit of 35

vulnerabilities in this domain. During the last five years, the aerospace community, AIAA, and the SURTC have felt and adapted to the cascading effects of the Great Recession, including spending cuts to the aerospace and defense industries, while at the same time continuing to improve the technologies of the future and improve their survivability through the scientific and technical exchange of ideas.

The AIAA Technical Activities Committee established the SURTC in 1988 with an official starting date of 1 May 1989 and the following charter:

To promote the development of survivability as an aerospace design discipline, including both the assessment (analysis and testing) of survivability and the development of technologies to improve survivability for fixed and rotary-wing aircraft and space systems. Aerospace survivability refers to the capability of a system to avoid and/or withstand hostile environments, man-made and otherwise (e.g., orbital debris, micrometeorites, bird strike). Susceptibility and vulnerability are the two pillars of survivability. Susceptibility is the inability of an aerospace system to avoid the hostile mission environment. Vulnerability is the inability of an aerospace system to withstand the man-made hostile environment. Other essential elements of survivability are crashworthiness and reparability (i.e., the ability to rapidly repair a damaged system). Aerospace survivability addresses threats that include weapons encountered in combat, adverse climatic conditions, and other environments hostile to an aerospace system (natural and man-made).

Year	Chairs	Institution
1989–1992	Dr. Robert E. Ball	Naval Postgraduate School
1992–1994	Mr. Nikolaos Caravasos	The Boeing Company
1994–1997	Mr. Donald J. Wallick	Institute for Defense Analyses
1997–1998	Mr. Eric R. Schwartz	The Boeing Company
1998–2000	Dr. Lloyd H. Smith	ASI Systems International
2000–2002	Mrs. Kathleen M. Atkins	Lockheed Martin Corporation
2002–2004	Dr. Joel E. Williamsen	Institute for Defense Analyses
2004–2006	Mr. Michael R. Weisenbach	Department of Defense
2006–2008	Mr. Ronald M. Dexter	SURVICE Engineering Company
2008–2010	Dr. Stephen R. Whitehouse	Applied Research Associates, Inc.
2010–2012	Mr. Alex G. Kurtz	United States Air Force
2012–2014	Mrs. Suzan L. DeRosa	Sikorsky Aircraft Corporation
2014–2016	Mr. Jaime J. Bestard	United States Air Force

Table 2 AIAA SURTC Chairs

The committee was founded by Dr. Robert E. Ball with the help of experts like Mr. Dale B. Atkinson, Mr. Nikolaos Caravasos, Dr. Lloyd H. Smith, Mr. John Vice, and Dr. Vincent Volpe. Table 2 lists all SURTC chairs, beginning in 1989 until the present time. The SURTC has recruited experts from academia, industry, and government since its inception, always seeking a healthy balance of technical know-how, supporting the susceptibility, vulnerability, crashworthiness, and reparability fields. Furthermore, the committee has always involved experts from the aircraft (both fixed and rotary wing) and space communities, as required to support the broader AIAA mission and maintain a robust exchange of information through the different communities and domains.

Since its early years, the SURTC collaborated within and outside the AIAA to garner broad support across the community. In fact, one of the first items in the committee's agenda was the co-sponsorship of the American Defense Preparedness Association (ADPA) [4] conference titled "Air Combat Survivability in a World of Modified Observables", featuring the survivability concerns arising from the emerging technologies of the time. In addition, the committee was concerned with the measures of effectiveness of contemporary electronic warfare equipment. At the time, the United States was emerging from the Cold War as the sole remaining superpower, and as a result of the break-up of the Soviet Union, troop levels and investment in defense were dramatically decreased. The nation, however, remained at the leading edge of technological innovation in the defense aerospace sector, as exemplified by the harnessing of digital technologies in aircraft design and optimization and the development of key survivability enhancement features, such as stealthy designs, which reduced susceptibility. Therefore, associating a diverse group of experts and allowing them to network enabled the survivability community to remain at the leading edge of technological innovation and ensure survivable aircraft and spacecraft designs during rapidly changing times.

The SURTC held one of its initial meetings in conjunction with the "Third Department of Defense and National Aeronautics and Space Administration Composites Repair

[4] Predecessor of the NDIA, which was formed in 1997 through a merger of ADPA with the National Security Industrial Association

[5] Predecessor of the Joint Aircraft Survivability Program, which is funded and overseen by the Director, Operational Test and Evaluation with the mission of achieving "increased affordability, readiness, and effectiveness of tri-Service aircraft through joint coordination and development of survivability (susceptibility and vulnerability reduction) technologies and assessment methodologies"

Technology" conference, highlighting reparability, one of the fields of interest in survivability. During that meeting, the committee discussed the dissemination of the Joint Technical Coordinating Group for Aircraft Survivability (JTCG/AS) [5] "Aircraft Fuel System Fire and Explosion Suppression Design Guide" to industry. In addition, the SURTC developed monographs for use in college aircraft and spacecraft design courses, including "How to Design a Survivable Military Aircraft," "Designing Survivable Aircraft Engines," and "Designing Survivable Spacecraft." At the time, the committee also sought to establish initial interaction between the aircraft combat survivability and the spacecraft communities.

On 29 September 1998, the SURTC held its 20th meeting in combination with the AIAA and Society of Automotive Engineers World Aviation Congress. The chair at the time was Dr. Lloyd H. Smith, one of the committee's founders. The meeting highlighted many of the principal committee activities, which were well established by then. The committee held two survivability sessions in the congress, and the AIAA Survivability Award was presented the day after the meeting to Mr. Nikolaos Caravasos "for 30 years of pioneering design and for the implementation of survivability improvements to fixed and rotary wing aircraft." At the time, the SURTC already had a website that was maintained by Mr. James E. Rhoads and sponsored by the Survivability/Vulnerability Information Analysis Center. [5] Furthermore, the committee, through Dr. Joel E. Williamsen, was involved in a United States Air Force summer study on orbital debris and spacecraft protection commissioned by the United States Space Command, leading to a presentation and white paper on spacecraft survivability given to the JTCG/AS Principal Members. The outcome of this last activity was forwarded to the AIAA Standards Committee to support the development of an AIAA Orbital Debris position paper. These efforts were closely related to the development of ballistic protection incorporated into the ISS to protect pressurized sections and critical systems.

Since autumn 1999, the SURTC has held its fall meetings in conjunction with the NDIA Aircraft Survivability Symposium in Monterey; and since spring 2000, it has held its annual meeting with the AIAA SDM Conference. Participation in these forums has given the committee the opportunity and flexibility to reach the aerospace community, both in classified and unclassified settings, allowing for more open discussions and encouraging growth within the discipline.

Survivability was a central component of the 2004 AIAA Undergraduate Design Project, which was possible with support from the SURTC through the exceptional efforts of Drs. Joel E. Williamsen, Robert E. Ball, and Leonard F. Truett, III. The project involved the design of an advanced gunship survivable against man-portable air defense system and anti-aircraft artillery. These requirements directly reflected the challenges faced by the United States during the War on Terror, Operation ENDURING FREEDOM in Afghanistan, and Operation IRAQI FREEDOM. The nature of the enemy in these conflicts focused the aerospace industry on persistence for the intelligence, surveillance, and reconnaissance and close air support missions, as well as major concerns from threats to low-flying aircraft (fixed and rotary wing, military, and civilian alike). In addition to these concerns, the SURTC had to make sure that all aspects of the project were detailed enough to be meaningful, yet generic enough to avoid classification issues, and simple enough to be part of an undergraduate-level design effort. This project was a paramount execution of the committee's core mission of promoting survivability as an aerospace design discipline.

On 11 January 2007, China conducted an anti-satellite test that stressed the serious consequences of engaging in the militarization of space, particularly as such tests contribute to the formation of orbital space debris, which remains in orbit for many years and interferes with the operations of all spacefaring nations. In 2010, Dr. Robert E. Ball published an article in *Aerospace America* entitled "Combining Safety and Survivability for Future Spacefaring," describing concerns and providing recommendations for spacecraft survivability based on aircraft lessons learned. These issues focused the SURTC on activities that addressed space asset survivability, particularly concerns from orbital debris impacting operational systems, both manned and unmanned. The committee, led by Dr. Stephen R. Whitehouse, participated in the development of two International Organization for Standardization (ISO) standards: ISO 16126, "Assessment of survivability of unmanned spacecraft against space debris and meteoroid impacts to ensure successful post-mission disposal" (ISO 16126, published on 24 March 2014) and "Prevention of break-up of unmanned spacecraft" (ISO 16127, published on 13 February 2014). Both standards address multiple concerns from the space survivability community.

During the last five years and after a sharp surge of troops into Afghanistan and Iraq in 2009, the United States and its allies withdrew from Iraq in 2011, and began a gradual drawdown in Afghanistan that has continued until 2014. These operations continue to have repercussions across the survivability community, particularly concerns with low-flying aircraft and

[6] Predecessor of the recently established (9 April 2014) Defense Systems Information Analysis Center helicopters, and the survivability of their occupants. The SURTC has up geared to support these activities by recruiting scientific and technical contributions that address crashworthiness and aircraft safety.

As the nation entered the Great Recession, the global economic downturn of 2009, all industrial sectors of the US economy, including aerospace and defense, were disrupted. This downturn led to blunt austerity measures with widespread effects across the aerospace and defense sectors, including AIAA and the survivability community. To minimize the impact of these measures, AIAA reshaped its conference model and merged multiple conferences into large forums, such as SciTech, which has been the SURTC's host venue for the last two years. These mergers have slightly changed the *modus operandi* of the committee, bringing new challenges while boosting networking and visibility and facilitating participation. While challenges are constantly arising, the SURTC continues advancing the survivability discipline by promoting participation in conferences, supporting the recognition of exceptional survivability experts, and sponsoring the publication of articles in scientific journals and publications with broad audiences.

TOMORROW'S SURTC

The SURTC has been a leader in the development of the aerospace survivability discipline for AIAA, the survivability, and the aerospace communities at large and will continue to do so in the future. The committee has been key in evaluating emerging technologies to identify susceptibility and vulnerability issues and improve survivability. As the nation concludes two wars and emerges from an economic recession and resulting austerity measures, new investments are being made into future aerospace technologies that will be considered and improved by the survivability community. This will ensure that these new technologies meet the rigorous standards that have been established through the years and the expectations of the American public when it comes to the combat survivability of their soldiers, the reliability of their space assets, and the safety and security of their civil aviation.

Figure 2 2014 AIAA Survivability Award Recipient, Mr. John M. Vice, receiving the award from Dr. Carlos Cesnik, 55th SDM Chair, and Mrs. Kathleen M. Atkins, AIAA Aerospace Design and Structures Group Technical Director and a former SURTC Chair

Emerging threats, such as directed energy weapons, have a high potential to be future game changers in combat and increase the vulnerability of air and space systems. Radar and detection technologies are constantly evolving to detect low observable aircraft, potentially making them susceptible. Growing quantities of orbital debris and crowded lower orbits raise concerns about the susceptibility, vulnerability, and overall survivability of operational space assets (manned and unmanned). In addition, limited resources bring new challenges and opportunities to develop alternative energy solutions and aerospace systems capable of exploiting new technologies efficiently. The survivability community at large is currently addressing all these challenges, while AIAA and the SURTC continue to provide venues for networking and bringing attention to concern and innovative solutions.

To keep providing relevant activities for the community, the SURTC will continue to participate in major AIAA and NDIA events and actively recruit participants to these forums through the publication of scientific and technical articles. The committee will continue to recruit nominations and manage the selection and presentation of the AIAA Survivability Award to recognize exceptional commitment to survivability. Through AIAA, the committee is preparing to develop public webinars and seminars and continue developing a professional cadre of survivability scientist and engineers while taking advantage of modern communication technologies. Finally, the committee will continue to sponsor articles in widely read publications to bring visibility and maintain support for the unique projects carried out by survivability experts. Today's SURTC continues to adapt and engage to address tomorrow's survivability concerns.

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