DSIAC JOURNAL

A Quarterly Publication of the Defense Systems Information Analysis Center

Volume 1 • Number 1 • Summer 2014

AIRCRAFT ENGINE

Exhaust Plume Phenomenology Modeling Improvements for Better HITL Scene Generation & Missile Endgame Performance (PAGE 16)

DSIAC JOURNAL

VOLUME 1 | NUMBER 1 | SUMMER 2014

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Cover Photo Credit: U.S. Air Force

The *DSIAC Journal* is a quarterly publication of the Defense Systems Information Analysis Center (DSIAC). DSIAC is a Department of Defense (DoD) Information Analysis Center (IAC) with policy oversight provided by the Assistant Secretary of Defense for Research and Engineering, ASD (R&E). DSIAC is operated by a team led by the SURVICE Engineering Company and includes Quanterion Solutions Incorporated, Georgia Tech Research Institute, Texas Research Institute Austin, and The Johns Hopkins University.

Department of Defense Information Analysis Centers

CONTENTS

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DIRECTORS' WELCOME

We are pleased to introduce the Defense Systems Information Analysis Center (DSIAC) and the inaugural issue of the quarterly *DSIAC Journal*. This inaugural issue is being widely distributed in both print and electronic form to provide the latest information about the new DSIAC and to serve as a ready reference for accessing its products and services, most importantly the free Technical Inquiry (TI) service (further described on **page 37**). Current and future issues of the *DSIAC Journal* can be found at **www.dsiac.org**.

The launch of DSIAC on 1 January 2014 marks a major milestone in the history of the Information Analysis Center (IAC) program—the final step in the Department of Defense's (DoD's) implementation of the "Better Buying Power" initiative to reshape the IACs and establish three consolidated Basic Centers of Operation (BCOs) in Cyber Security & Information Systems, Homeland Defense, and Defense Systems. This transformation better aligns the IAC program with the contemporary budget environment and positions the IACs to effectively meet the emerging needs of their respective technical communities by

1. Aligning IAC focus to match the top priorities of the Secretary of Defense
2. Increasing synergy across related technology areas
3. Increasing opportunities for small business
4. Lowering cost and improving quality through enhanced competition, and
5. Expanding the industrial base accessible through the IACs

From the creation of the first DoD-sponsored IAC in December 1946 until today, IACs have served as a critical value-added resource to improve productivity and reduce redundancy in DoD research and engineering efforts. IACs connect engineers and scientists with the vast repository of DoD scientific and technical information (STI) to fully exploit the knowledge base and benefit the greater DoD community. The long and rich IAC heritage that has led to today's DSIAC is illustrated on **page 22**.

DSIAC SCOPE AREAS

Advanced Materials
Autonomous Systems
Directed Energy
Energetics
Military Sensing
Non-Lethal Weapons
Reliability, Maintainability, Quality, Supportability and Interoperability (RMQSI)
Survivability & Vulnerability
Weapon Systems

The transition of the core operations of the six legacy IACs (AMMTIAC, CPIAC, RIAC, SENSIAC, SURVIAC, and WSTIAC) was completed on 27 June 2014, when DSIAC assumed full responsibility for their respective technical scope areas. Further, DSIAC is responsible for supporting three new areas: Autonomous Systems, Directed Energy, and Non-Lethal Weapons. To accomplish this broad mission, DSIAC is establishing nine distinct Communities of Practice, which will foster communication and collaboration and help DSIAC users to focus on their particular areas of interest.

One core function of DSIAC is to acquire, organize, catalog, and disseminate STI. Accordingly, we seek reports, papers, data, and other formal documentation (classified or unclassified) for permanent indexing and cataloging in the Defense Technical Information Center (DTIC) digital Research & Engineering (R&E)

continues on page 4

Tom Moore is the DSIAC Director and an employee of the SURVICE Engineering Company. He is a 30-year veteran of the Defense industry, having served in various engineering and senior program management positions at Alliant Techsystems (ATK), Hercules Aerospace, and the Chemical Propulsion Information Analysis Center (CPIAC), where he served as Deputy Director. He holds an M.S. in Technical Management from The Johns Hopkins University (JHU) and a B.S. in Mechanical Engineering from West Virginia University. He is a certified Project Management Professional (PMP) and Associate Fellow of the American Institute of Aeronautics and Astronautics.

Christopher Zember was named Director of the Department of Defense (DoD) Information Analysis Centers (IACs) in December 2012. In this position, he is responsible for the overall operational management and policy guidance for the DoD IACs enterprise, including the IAC Basic Centers of Operation (BCOs) and the Technical Area Tasks (TATs) Multiple-Award Contracts. Prior to his current position, he led the Strategy and Operations practice for a consulting firm and served as a liaison officer for the National Security Agency. He holds a Master of Public Administration from American University and a B.A. in English from Harding University.

Gateway. Please contact DSIAC if you are aware of orphaned or otherwise uncataloged technical reports or collections that deserve to be indexed and permanently archived for future use by the greater DoD technical community.

Likewise, a key objective of the DSIAC transition philosophy has been to capture the best practices of each IAC and provide the most seamless transition possible for the six legacy technical communities. We applaud the legacy IAC operators—Alion Science and Technology, The Johns Hopkins University (JHU), Wyle Laboratories, the Georgia Tech Research Institute (GTRI), and Booz Allen Hamilton—for their longstanding contributions to the IAC program and thank them for their support in the transition to the new DSIAC.

In conclusion, DSIAC is extremely pleased to join the Cyber Security and Information Systems Information Analysis Center (CSIAC) and the Homeland Defense and Security Information Analysis Center (HDIAC) as the next generation of DoD IACs. The partnership, experience, and resources of the DoD IAC Enterprise team stand ready to help address the challenges and needs of the U.S. Government, the DoD, and the industrial complex. Whether you are part of a legacy IAC technical community, are interested in any of our new scope areas, have a question, or require more substantial technical support, DSIAC looks forward to hearing from you. Call us at 443.360.4600, visit the website at **www.dsiac.org**, or send an e-mail to **contact@dsiac.org**. ■

MESSAGE FROM THE COR

Brad Forch is the Senior Research Scientist for Ballistics at the Weapons & Materials Research Directorate, U.S. Army Research Laboratory (ARL), Aberdeen Proving Ground, MD. His 28-year Army research expertise covers a wide range of ballistic sciences, including the chemical and physical mechanisms behind chemical energy storage, ignition, combustion, and release in propellants and explosives (including weapons materials and novel energetic material structures for weapons). He holds a Ph.D. in Physical Chemistry/ Chemical Physics from Wayne State University and B.S. and M.S. degrees from Illinois State University. He was a National Academy of Sciences/National Research Council postdOctoberoral Fellow tenured at the U.S. Army, is currently a member of the JANNAF Executive Committee, and is an ARL Fellow.

I enthusiastically accepted the opportunity to become the Contracting Officer's Representative (COR) for the new Defense Systems Information Analysis Center (DSIAC), which is now rapidly expanding the combined capability of its legacy components. DSIAC is exploring new and creative methods to significantly improve systems and processes to collect, analyze, synthesize, disseminate, and communicate scientific and technical information (STI) to meet the current and future needs of researchers, engineers, and program managers in the Defense research, development, and acquisition communities.

One such example is DSIAC's implementation of Communities of Practice, which leverages a wide variety of community-centric tools and methods to enable a collaborative, real-time awareness of evolving technical challenges and developments and enhanced STI sharing. The enormously increasing volume and availability of STI from digital media have vast implications and demand new approaches to accelerate the translation of data-to-decisions, provide rapid and accurate solutions to complex operational problems, save resources, reduce the acquisition timeline, and meet urgent Warfighter needs.

To help meet this challenge, DSIAC is implementing a wide range of authorized user self-service and assisted STI services that provide quick answers and are optimized for cost-efficient reuse of existing information to eliminate duplicative activities. Although the pace of technology development worldwide is overwhelming, it is the United States' tenacity at maintaining our capabilities in research and engineering discovery, innovation, and transition that is a key tenant in maintaining our leadership in Defense.

DSIAC is also strategically positioning its efforts to monitor, access, and extract global STI to analyze trends, predict future directions, avoid technological surprise, and empower our capabilities to speedily enable new or extended military capabilities. In doing so, the IAC has certainly assumed leadership for an enterprise that represents a cross section of many Department of Defense critical core competencies.

Finally, in an environment of increasingly disruptive change, DSIAC has carefully engineered into its organization foundation the agility to respond to that change and the capability to anticipate and proactively create the change needed for the dynamic Defense Systems environment. ■

THE BETTER BUYING POWER INITIATIVE: A NEW IAC PARADIGM

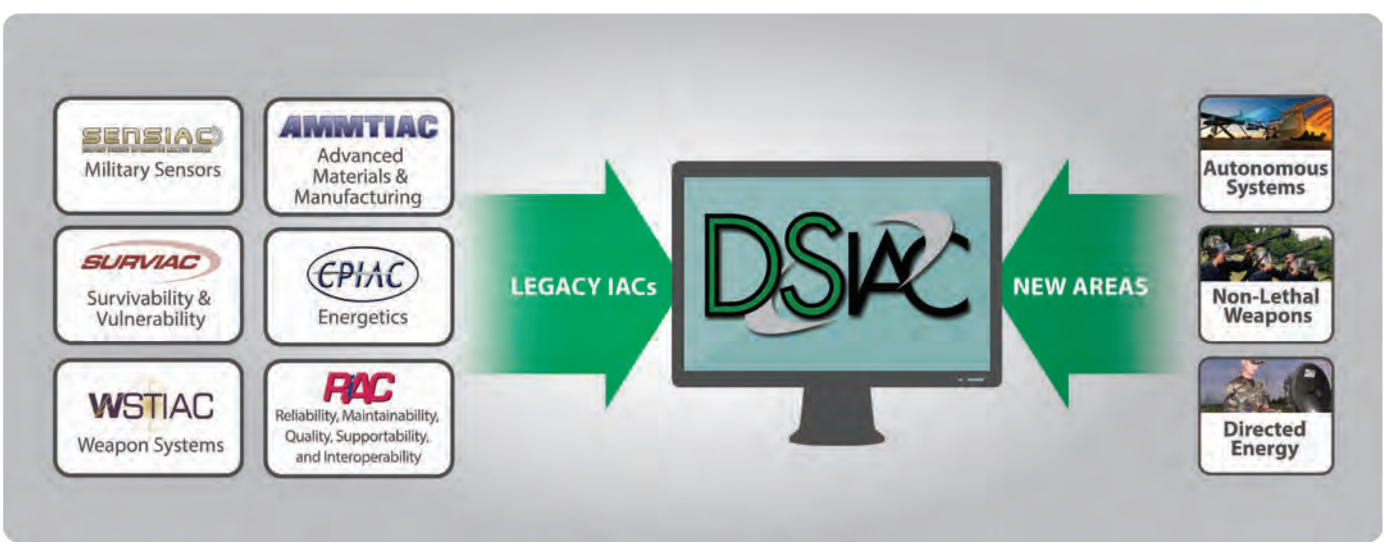
In the current budgetary environment, the Department of Defense (DoD) continues to demonstrate its ability to sustain a high level of performance by adapting to financial challenges with strategies that address affordability. An essential DoD resource that has traditionally supported this imperative is the DoD Information Analysis Centers (IACs) enterprise. DoD IACs continue to operate under the policy leadership of the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)) and are administered by the Defense Technical Information Center (DTIC). While the IACs have taken many positive steps to provide the DoD community with value-added services that support the affordability imperative, there is more work to be done to get the IACs directly supporting acquisition milestone decisions and the Better Buying Power (BBP) initiative.

As the ASD(R&E) nears completion of the largest IAC reorganization in history, the foundation for a leaner, more efficient, and more synergistic IAC system is in place. Shared processes and operational commonality of the three new IACs (the Defense Systems Information Analysis Center [DSIAC], the Cyber Security & Information Systems Information Analysis Center [CSIAC], and the Homeland Defense & Security Information Analysis [HDIAC]) will provide DoD and related community clients a streamlined, standardized process for gaining access to the wealth of information that has been captured over the last 60 years.

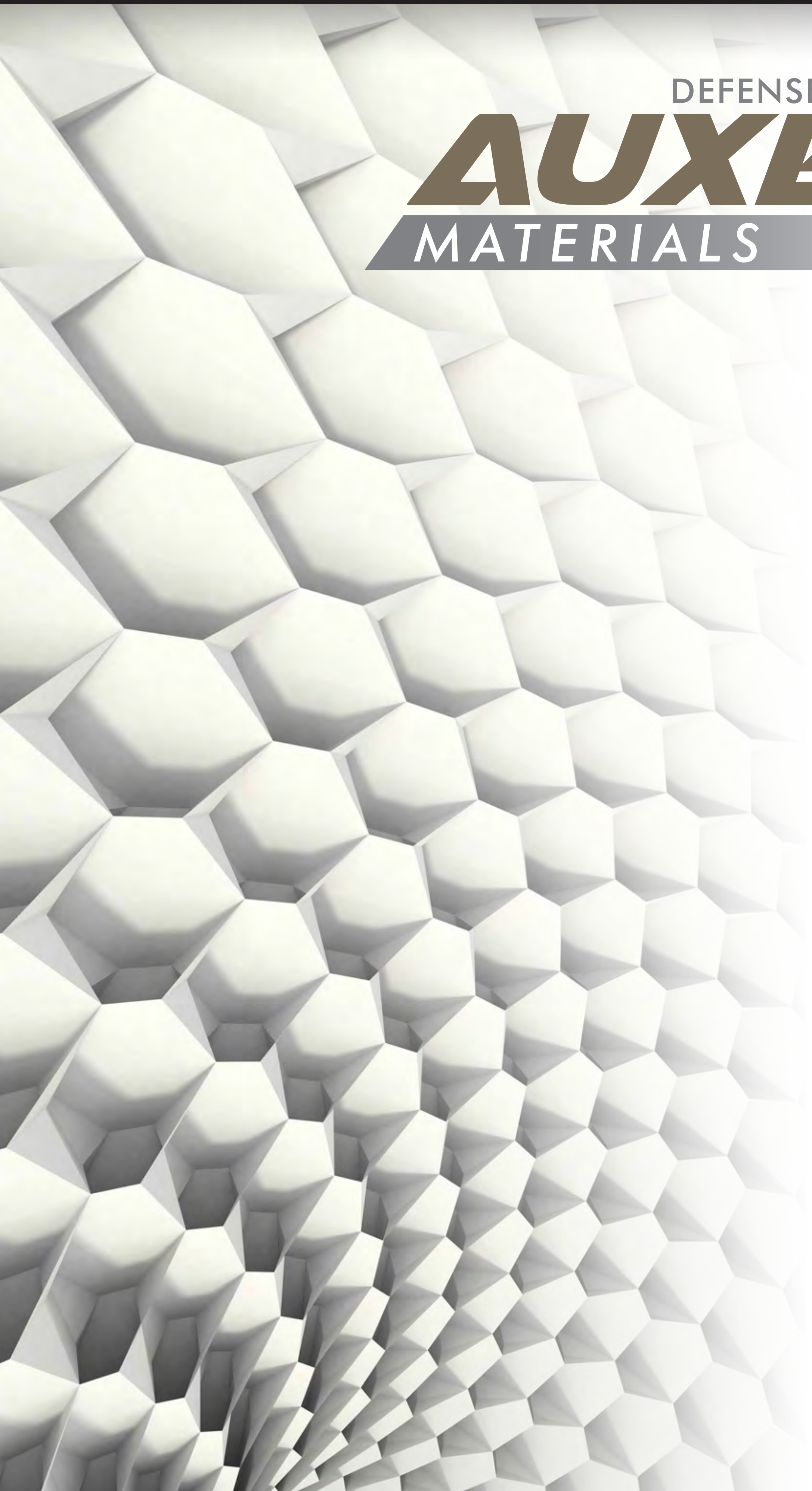
The new construct enables the DoD IACs enterprise to achieve efficiencies identified by the Secretary of Defense. The objectives of the reorganization are to:

- Align the focus of IACs with priorities of the Secretary of Defense for the BBP initiative
- Leverage synergies between related IAC technology domains
- Reduce cost and improve quality with increased competition from small businesses
- Expand industrial base accessible through IACs.

The incorporation of three new functional subject areas and the consolidation of the legacy IACs into DSIAC represent the largest IAC merger to date. DSIAC covers a broad range of Defense Systems information, which is all available via a single entry point. As DSIAC completes the transition later this year, we look forward to being your primary source for timely and relevant scientific and technical information (STI). ■



DEFENSE APPLICATIONS OF AUXETIC MATERIALS



By Royale Underhill

INTRODUCTION

During military operations, personnel and vehicles are often exposed to ballistic and blast threats. Lightweight armor systems are used in situations where there are weight restrictions, such as with personal protection, helicopters, patrol boats, and transportable shelters.[1] The ideal material for use in an armor system must absorb energy locally and be able to spread the energy out fast and efficiently.[1] This paper introduces a novel class of material, auxetic. It has been postulated that auxetic materials have these properties[2] and as such have potential for use in a number of defense applications, including armor systems.

When a material is stretched, it is expected that it will become thinner in the direction perpendicular to the direction of stretch. This expectation is because a large portion of materials, both naturally occurring and man-made, respond in this manner. Such materials have positive Poisson's ratios. Conversely, auxetic materials, which have a negative Poisson's ratio, become thicker when stretched. These negative Poisson's ratio materials will also contract in the directions orthogonal to a compressive load. When the material contracts, it becomes more dense, increasing indentation resistance.[3] It is this property that is of interest from a defense point of view. These materials are predicted to have exceptional resistance to blast and ballistic threats, while not contributing to excessive weight compared to conventional materials.[4] The improved mechanical properties of negative Poisson's ratio materials may result in both lighter and thinner materials for use in protection.

For an isotropic material, the mechanical properties of which are the same in all directions, the Poisson's ratio υ is a measure of how the material responds when stretched, and is defined by Equation 1, where ε_x is the tensile strain in the stretching direction and ε_y is the tensile strain perpendicular to the stretching direction.

(1) $$\upsilon = \frac{-\varepsilon_y}{\varepsilon_x}$$

Most materials have a positive Poisson's ratio (e.g., natural rubber is ½, steel is ⅓). That is, they contract perpendicular to the direction of stretch (Figure 1A). In these cases, ε_y is negative, so the overall Poisson's ratio is positive. However, if the material expands perpendicular to the direction of stretch (Figure 1B), then both ε_x and ε_y are positive and the Poisson's ratio is negative. The Poisson's ratio can vary between -1 and +½ (Equation 2). More than a century of theory has predicted the possibility of negative Poisson's ratio materials. It wasn't until 1987 that Lakes first demonstrated a man-made cellular polyurethane foam with a Poisson's ratio of -0.7.[6] In 1991, Evans named these materials "auxetics" from the Greek *auxetos*, meaning "that which may be increased."[7]

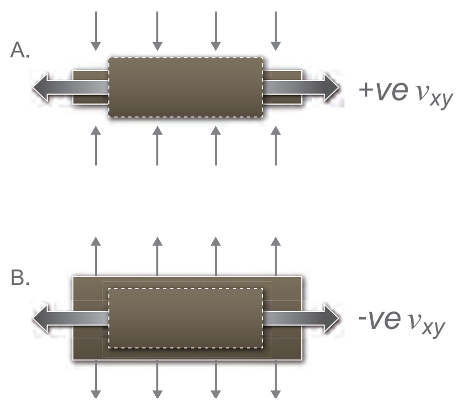


Figure 1: Illustration of Deformation for (A) Positive Poisson's Ratio Materials, (B) Negative Poisson's Ratio Materials. Image Reproduced From Auxetnet Website.[5]

(2) $$-1 \leq \upsilon \leq +\frac{1}{2}$$

A negative Poisson's ratio is associated with increased shear modulus,[8] indentation resistance,[3] and fracture toughness.[9] For example, the shear modulus G is related to the Poisson's ratio by Equation 3, where E is the Young's modulus. As υ approaches -1, G becomes infinitely large. The elastic indentation resistance H is proportional to the square of the Poisson's ratio, as given in Equation 4, where x varies according to the analytical theory used; and for negative Poisson's ratios, the indentation resistance may increase greatly (especially for $-1 \leq \upsilon \leq -½$). Such properties may lend themselves to a wide range of applications, such as helmets, bullet proof vests,[10] shin pads, and knee pads.[9] Potential applications are not limited to personal protective equipment: due to their enhanced energy absorption properties and fiber pullout resistance,[11–13] auxetic materials can be used as robust shock absorbers, air filters, fasteners, electrodes for piezoelectric sensors,[10] and sound absorption.[3]

(3) $$G = \frac{E}{2(1+\upsilon)}$$

(4) $$H \propto (1-\upsilon^2)^{-x}$$

The auxetic materials fabricated to date are porous polymeric and metallic foams, microporous polymers, honeycomb structures, and yarns. These structures are dependent on the basic two-dimensional phenomena seen in Figure 2; force in the vertical direction results in the "opening" of the horizontally placed arms (like the opening of an umbrella). This simple mechanism can be built up to yield a network re-entrant structure, as seen in Figure 3. The fibril/nodule structure shown in Figure 4 is an alternate way to produce materials with negative Poisson's ratios. The nodules are interconnected by fibrils. When the material is put under tension, the fibrils align, causing the nodules to push apart.[14, 15] Based on elastic theory, these auxetic behaviors are scale-independent;[7, 16] hence both macroscale and molecular auxetic materials are possible.

Another benefit of auxetic structures is that they exhibit synclastic curvature. Synclastic curvature describes a surface that bends in the same direction in both perpendicular planes (Figure 5(a)). That is, something with synclastic curvature conforms to a dome shape—for example, a helmet or knee pad—without needing seams or joining. Synclastic curvature

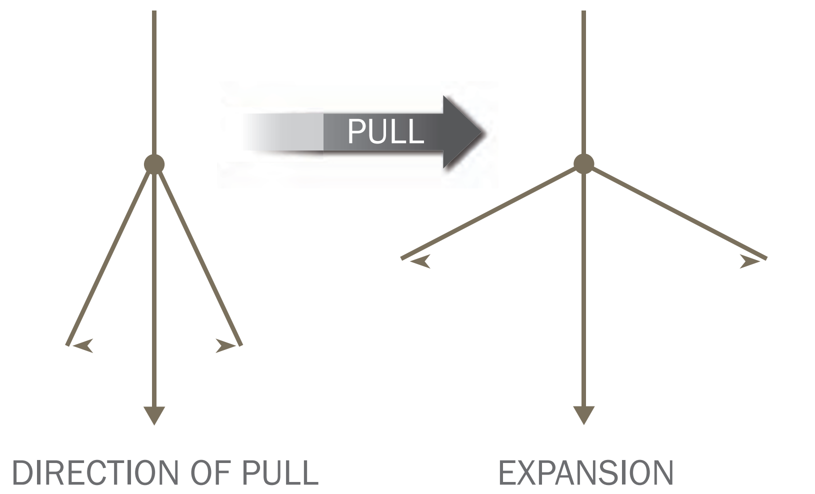


Figure 2: Basic Deformation Mechanism for Auxetic Materials. An Applied Tension in the Vertical Direction Causes the "Opening" of the Arms, Resulting in Expansion in the Direction Perpendicular to the Force.

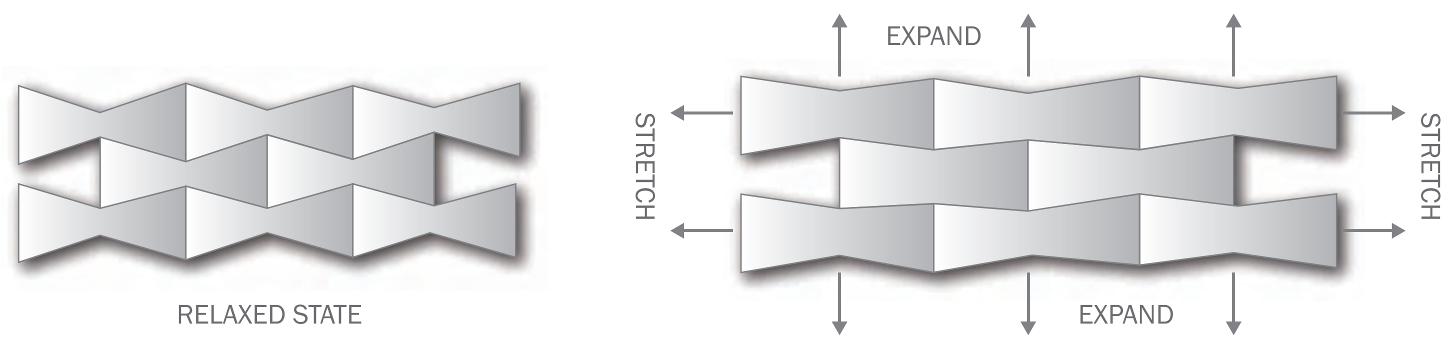


Figure 3: Basic Re-Entrant Network Structure. As the Structure Is Stretched Horizontally, the "Bow-Tie" Structures Open Vertically, Resulting in Expansion in the Direction Perpendicular to the Force.

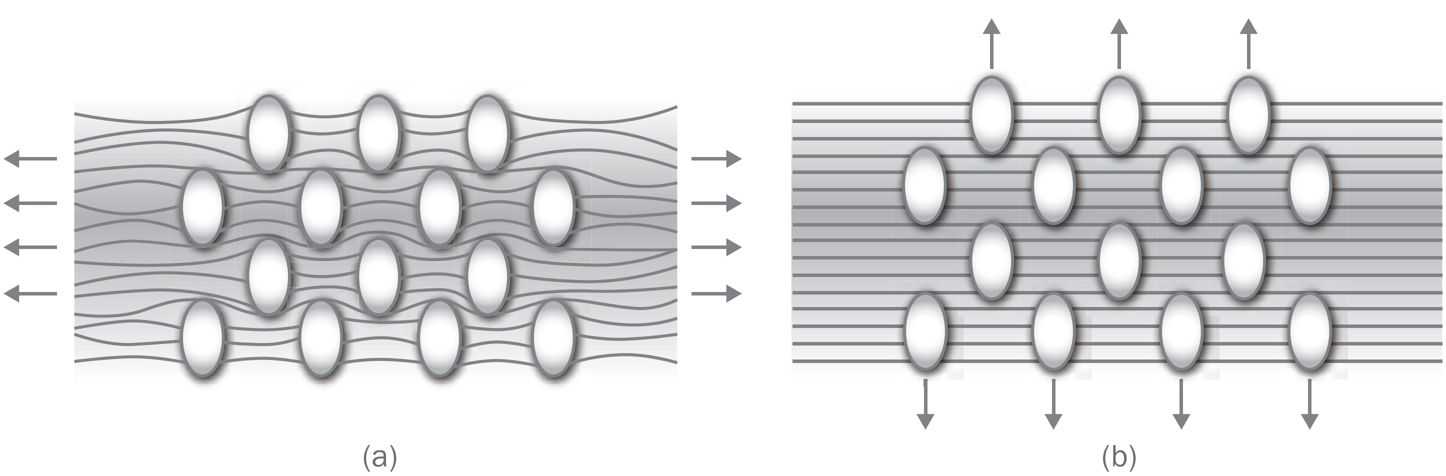


Figure 4: Nodule/Fibril Structure. (a) Slack Fibril/Nodule Structure with Direction of Stretch Illustrated. (b) Stretched Fibril/Nodule Structure with Direction of Expansion Marked.

would also be useful in parts manufactured for aerospace applications, such as wing panels or nose cones. Most materials are anticlastic, which yields a saddle-shape structure (Figure 5(b)).

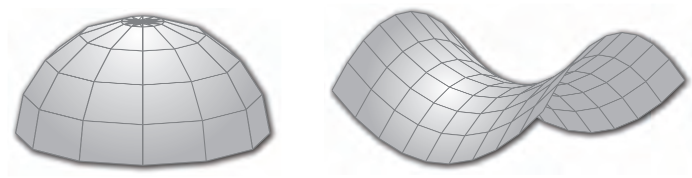


Figure 5: Example of Curvature for Planar Materials. (a) Basic Hemisphere, Example of an Synclastic Structure. (b) Basic Saddlepoint, Example of an Anticlastic Structure.

FABRICATION

Auxetic materials can be made from a variety of polymers or metals. Many synthetic routes are possible; the most common auxetic material is a foam, which can be achieved by producing a re-entrant cell structure. The method for obtaining these foams from polymers is a four-step process: (1) compression, (2) heating, (3) cooling, and (4) relaxation.[6] To transform a conventional polymeric foam into an auxetic one, it must be compressed in three dimensions simultaneously, forcing the walls of the bubbles in the foam to buckle.

Another method for achieving auxetic polymers (not foams) is based on conventional powder processing techniques, which rely on compaction, sintering, and extrusion. The resulting auxetic material exhibits an interconnected network of nodules (particles) and fibrils.[14] Microporous polytetrafluoroethylene (PTFE) (also known as GORE-TEX®) is produced this way. The auxetic properties are due to the microstructure rather than any intrinsic property of the polymer used.[17] Evans et al.[8] have shown that other polymers, such as ultra-high molecular weight polyethylene (UHMWPE), can be processed in a similar manner to produce auxetic materials. They can be achieved using a three-step process: (1) compacting UHMWPE powder at elevated temperature, then (2) sintering, followed by (3) extrusion.[17] This method yields materials that are stiffer than the auxetic foams and have comparable moduli to conventional thermoplastic polymers.

A third possible method for organic auxetic materials is a molecular design approach. This approach relies on building the auxetic response directly into the molecule or its interchain packing distance.[19] There are a few different approaches to molecular design. One uses liquid crystal polymers (LCP).[19–22] LCP auxetics require specific site-connectivity. This method is a variation on the fibril/nodule structure. Rods are laterally (transversely) attached between linear polymer segments. In their relaxed (unstretched) state, the rods are aligned parallel to each other and the polymer chain axis; but under a tensile stress, the chain forces the rods to rotate. The resulting positions normal to the polymer chain axis; may lead to expansion, if the rods are sufficiently long.[19] Molecular modeling has shown that rods containing molecular structures seven rings long were needed to achieve negative Poisson's ratios.[23] The same modeling predicts that the LCP need to incorporate 50% rods before a significant change in Poisson's ratio is observed.[23] LCP have been synthesized,[19–22] but to date none has exhibited a negative Poisson's ratio. X-ray scattering experiments on these materials suggest that, under tensile strain, rod-reorientation occurs, giving rise to an increase in the interchain distance for these polymers,[21] These LCP materials are a step in the direction of achieving negative Poisson's ratio, and if the synthesis can incorporate the findings from the molecular modeling, an auxetic material may be achieved.

Another molecular design method uses three-dimensional tesselated polymer networks. Of the tesselated networks, a number of strategies have been examined: "reflexyne" polyphenylacetylene networks,[24] which mimic the re-entrant structure of foams; "polytriangles," also made from polyphenylacetylene networks,[25] which rely on rotating triangles; and "polycalixes," based on calixarenes,[26] which will open like umbrellas when a force is applied. All these approaches have been explored through simulation, although none has been synthesized.

A fourth method to achieve auxetic materials involves composite structures. There are two main approaches to auxetic composites: a laminated angle ply, which relies on the architecture of one of the phases,[27–30] and a composite, where one or more of the phases is auxetic.[31] A fifth method involves weaving an auxetic textile. In this method, none of the base filaments exhibits a negative Poisson's ratio; it is the geometry of the yarn that produces the auxetic effect. This was first shown by Hook and Evans.[2] The multi-filament can be produced by wrap-spinning as well as warp- or weft-knitting.[32,33] The auxetic yarns can subsequently be woven or knitted into fabrics with auxetic properties.

POTENTIAL DEFENSE APPLICATIONS

Auxetic materials may show improvements over conventional materials because of the negative Poisson's ratio, which has been predicted to contribute to improved toughness,[34] resilience,[35] and shear resistance,[36] as well as improved acoustic properties associated with vibration.[31,37] Exploration into the unusual properties of these materials has been supported by NASA,[36] Boeing,[38] and the U.S. Office of Naval Research.[31, 37, 39]

These materials have the potential to revolutionize defense personal protective equipment. Current protective materials are stiff and heavy. Auxetic materials may be able to provide the same protection while being thinner and consequently lighter. The synclastic curvature available from auxetic materials makes it easier to manufacture curved surfaces that conform to the human body (e.g., knee pads, helmets). When an auxetic helmet is impacted, material flows into the area to provide reinforcement. This allows less deflection on the interior of the helmet, allowing for less injury to the human wearing the helmet. Recently, the U.S. Office of Naval Research (ONR) has even solicited proposals for "Applications of Auxetic Textiles to Military Protective Clothing" under the Small Business Technology Transfer (STTR) program (TopicN12A-T012).[40]

Auxetic materials also have applications in the broader topic of energy absorption materials. Energy absorption materials can be anything from an explosion-resistant coating (ERC) to the energy-dissipating material (EDM) used to cushion airborne cargo drops. Current EDM is a paper honeycomb product designed to collapse on impact, absorbing and dissipating the kinetic energy. The impact and indentation resistance of auxetic materials makes them a good candidate for this application. Auxetix Ltd. has developed a helical auxetic yarn that the company is marketing as a potential material to make blast curtains.[2]

> ...materials may result in both lighter and thinner materials for use in protection.

Auxetic materials are not limited to protection applications in their usefulness. Because auxetic materials will expand perpendicular to a force, they will make ideal press-fit fasteners and rivets.[39] An auxetic fastener, when inserted into place under compression will contract, making installation easier. It will then expand when put under tension, thus sealing itself more effectively into the hole.[39] The contraction while compressed also lends to improved projectile materials. As a projectile moves down the barrel, the thrusting force would potentially result in a reduction in lateral expansion.[17]

Similar to making good fasteners, auxetic fibers will also make good reinforced composites. Fiber pull-out is a major failure mechanism in conventional fiber-reinforced composites. With auxetic fibers, pull-out is resisted because the fibers expand perpendicular to the pull-out force. This characteristic could help to resist potential failure mechanisms in the composite, such as crack growth. It has also been suggested that auxetic materials could be used in the design of hydrophones and other sensors because their low bulk modulus makes them more sensitive to hydrostatic pressure.[41] In 1991, the U.S. Office of Naval Research funded the evaluation of the theoretical performance of auxetic composites for piezocomposite devices.[42]

There are also a number of other applications, while not exclusive to defense, that are noteworthy. Auxetic materials have applications in the medical community as arterial prostheses, surgical implants, or suture/anchors.[12] Auxetic foams are proposed as good filters because of the ability to tune the pore size to the applications, as well as using tension to open the pores for cleaning. Auxetic foams used as cushions might be beneficial in the reduction of pressure-induced discomfort in people who are required to sit for long periods of time.[43]

Auxetic fibers may be incorporated into multi-filament yarns for weaving into smart textiles. One instance is the "smart bandage"; as a wound swells, it applies pressure to the bandage, opening the microstructure and releasing anti-bacterial compounds incorporated into the bandage. As the wound heals, the swelling decreases, putting less pressure on the bandage, which in turn releases less medicine.[2,44] Another potential application for auxetic fibers is in seat belts and safety harnesses. A conventional seat belt, when it restrains the occupant in an accident, stretches and becomes narrower. This narrow material then localizes the force on the occupant's body so that the individual may survive the accident, but have seat-belt-induced injuries. An auxetic seat belt would get wider as it stretches, thus spreading the load over a larger area, potentially reducing any injuries.[2,44] These same auxetic multifilaments may be used in auxetic blast curtains or blast-resistant blankets.[44]

LIMITATIONS

Microporous auxetic materials work because their porous structure allows sufficient space for the "hinges" to fold or the "nodules" to spread apart. Unfortunately, this same porous structure also leads to lower stiffness and lower density, which are unsuitable for load-bearing applications.[32,45] A further limitation with microporous auxetic materials is the inability to produce them reliably and cost-effectively using techniques that are suitable for large-scale commercialization.

One approach to overcome the problem with production scale is to develop molecular auxetics; however, this approach has its own limitations. One such limitation lies in synthesizing the highly symmetric, network-like structures. Theoretically, a number of molecular auxetics, such as honeycombs and egg-crate-like structures, are auxetic, but to achieve such structures in a polymer molecule would require intricate synthetic finess and a high degree of cross-linking, which would yield a brittle, stiff, and unprocessable polymer. If molecular auxetics can be achieved using a combination of auxetic structures and linear segments to make them easier to synthesize and process, then they may find use in the applications described.

CONCLUSIONS

Polymeric auxetic materials are a promising new area for exploitation in defense applications. This paper has discussed some of the unique physical properties of auxetic materials and various approaches to achieving them. The key to using auxetic materials in future applications is their successful synthesis and development. Despite an abundance of papers on the theory of auxetic materials, at present only microporous foams and yarns have shown negative Poission's ratios experimentally. A successful auxetic material will be one that can be produced on a commercial-scale, with the desired properties. ■

BIOGRAPHY

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TRAINING

DSIAC provides a wide range of on-site and off-site training programs to Government and industry organizations. Our extensive technical knowledge, proven instructional expertise, and real-world experience in providing engineering and consulting services throughout DSIAC's technical scope areas results in training that is comprehensive, practical, and effective. The following are some of the training courses that DSIAC currently provides.

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INSENSITIVE MUNITIONS
WHERE ARE WE NOW?

By Mike Fisher

Anyone involved in weapons systems development during the past 30 years should be familiar with the seemingly contradictory term "Insensitive Munitions" (IMs). According to MIL-STD-2105D, *Hazard Assessment Tests for Non-Nuclear Munitions*, IMs are:

"Munitions which reliably fulfill (specified) performance, readiness, and operational requirements on demand but which minimize the probability of inadvertent initiation and severity of subsequent collateral damage to the weapon platforms, logistic systems, and personnel when subjected to unplanned stimuli."

In other words, IMs generally describe those munitions that will not react to unintentional stimuli, such as fast or slow heating or bullet or fragment impact, in such a way as to cause catastrophic collateral damage that impairs warfighting capability. Originating in the 1970s as a response to devastating shipboard munitions fires (such as that shown in Figure 1), the IM initiative has grown from a Navy firefighting and cookoff program to a Department of Defese (DoD)-wide effort to reduce the sensitivity of all munitions, from small-caliber rounds to large-diameter strategic missile systems. In the past 20 years, the IM cause has taken root in other parts of the world as well, most notably in the NATO Allied Nations, driven by interoperability requirements for NATO weapons. The establishment and continued successful operation of the NATO Munitions Safety Information Analysis Center[1] (MSIAC) at NATO Headquarters in Brussels have significantly impacted the spread of IM knowledge and technical capability among NATO member nations' armed forces.

Many substantial improvements in munitions safety have been achieved through the combined efforts of the international weapons and energetics research communities. New plastic bonded explosives (PBX) and melt-cast formulations have reduced or eliminated the inadvertent detonation threat for many bombs and missile warheads. Design concepts that mitigate violent responses, such as venting systems and composite cases, have been successfully employed on rocket motors, warheads, guns, and ammunition systems. And solid propellants for gun and rocket propulsion systems have been formulated to reduce sensitivity to thermal decomposition and shock. As a result, the weapons portfolios of today's military are indeed much safer than those of past decades. MSIAC's IM State of the Art resource captures many of the latest technology developments, as well as tracks trends in IM design maturity and performance for various munition groups. This resource illustrates the significant and increasing number of reduced vulnerability systems that have entered service or are in development in the United States and other MSIAC member nations.[2]

Figure 1: USS *Forrestal* Aircraft Carrier Fire Caused by Weapon Cookoff.

Despite the undeniable advances made in IM system design, several significant challenges remain for researchers to overcome. The Office of the Secretary of Defense (OSD) directs a robust 6.2/6.3 technology development and demonstration program, the Joint Insensitive Munitions Technology Program (JIMTP), aimed at providing solutions to these challenges. The JIMTP is "a joint, focused science & technology program with the goal of developing and demonstrating enabling technologies so that future weapon systems can become IM compliant."[3] JIMTP efforts are focused in five major areas, known as Munition Area Technology Groups (MATGs), including high-performance and minimum-smoke rocket propulsion, blast fragmentation and anti-armor warheads, and large-caliber gun propulsion. Research and development (R&D) tasks, based on Program Executive Office (PEO)-identified technology gaps, cover development of new energetic and component technologies, as well as the integration of new IM technologies into system-level demonstrations.

One IM requirement that continues to challenge technologists—and generate a significant amount of debate within the international munitions safety community—is the mitigation of the response to shaped charge jet (SCJ) impact. This threat, typical of a variety of rocket-propelled grenades (RPGs) and top-attack bomblets, is recognized as one of the most difficult IM challenges due to the high-velocity SCJ generating intense shocks in energetic materials.[4] The violence of the SCJ attack is typically scaled using a parameter called V^2d, where V is the velocity of the jet and d is the jet diameter (Figure 2).

In the NATO Standard Agreement covering SCJ attack testing, STANAG 4526 Edition 2: *Shaped Charge Jet – Munitions Test Procedures*, four representative V^2d values are defined to represent different sizes of shaped charges (Table 1).[4]

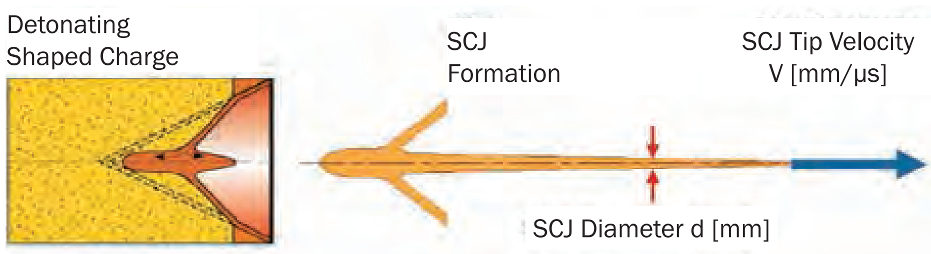

Figure 2: Illustration Of Shaped Charge Jet Diameter (d) and Velocity (V).[5]

Table 1: Representative V^2d Values for Different Shaped Charges.

Threat	Representative V^2d ($mm^3/\mu s^2$)
Top Attack Bomblet	200
SCJ with Characteristics of 50-mm Rockeye	360
Rocket-Propelled Grenade	430
Anti-Tank Guided Missile	800

Issues have arisen within the munitions safety community regarding the accuracy of the V^2d values in the STANAG and whether they represent the correct aggression levels for the threats identified for particular munition systems. Test parameters and measurement techniques can have significant effects on V^2d values, and SCJ impact test results. Additionally, in some of the MSIAC member nations, the standard 50-mm Rockeye called out in the test procedure is unavailable, precluding its use in the SCJ impact testing. Because of these and other inconsistencies and variations in testing performed by test centers within the NATO member nations, the need exists for review and modification of the relevant agreements and test requirements.

To address this situation, MSIAC held a workshop on SCJ assessment in May of this year. At the IM and Energetic Materials Technology Symposium in October 2013, MSIAC expressed the goals of the SCJ Assessment Workshop:[6]

Development of an assessment methodology for SCJ attack, with improved understanding of reaction mechanisms

- *Recommendations for improving STANAG 4526 SCJ all-up-round test based on a sound scientific understanding*
- *Identified capability gaps with recommendations on improvements*

- *Exploitation of scientific understanding, small-scale tests, and modeling to support IM assessment*
- *Inroads to IM assessments based on whole body of evidence approach vs. single all-up-round test results to improve confidence in assessment.*

Findings and recommendations resulting from the MSIAC workshop will be reported once the proceedings and final reports are made available.

So, where are we now with IM? Our munitions are less vulnerable to attack than ever before because of the technologies, design approaches, and implementation policies delivered by the munitions safety community. Although challenges remain, resources are in place to address current and evolving threats and to provide designers and program managers with viable system-level approaches to achieving compliance with IM requirements. ■

BIOGRAPHY

MIKE FISHER is a senior staff engineer for DSIAC. During his 30-year career, he has supported IM programs in a variety of roles—in IM technology design and implementation of policy for the Navy, in the transition of IM technology and assessment methodology to NATO nations as a technical specialist officer at MSIAC, and in the development of IM mitigation technologies through the Small Business Innovation Research (SBIR) program. He has also presented numerous technical papers on IM design, testing, and assessment at conferences and workshops in the United States and abroad; and he holds several patents for munition venting concepts.

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THE 96TH TEST WING: EXCELLING IN SEEKER AND SENSOR DATA COLLECTION

By Rusty Bauldree

The 96th Test Wing's Seekers and Sensors Test Flight provides an end-to-end test and evaluation capability for electro-optic/infrared (IR) and radio frequency (RF) systems and threat system performance to support weapons system platform survivability programs; camouflage/concealment and deception assessments; and countermeasure and counter-countermeasure, threat system exploitation, blue system effectiveness, and vulnerability studies.

This extensive weapon systems performance and target signature measurement capability provides calibrated data across the full electromagnetic spectrum, including ultraviolet (UV), visible, short-wave infrared (SWIR), mid-wave infrared (MWIR), and long-wave infrared (LWIR) broadband; MWIR, LWIR, and UV spectral; SWIR and MWIR hyperspectral; and millimeter-wave (MMW) C, X, Ku, Ka, and W RF bands—all fully coherent and fully polarimetric (VV, VH, HV and HH transmit and receive channels) with 2-GHz bandwidth capability. Flexible air/ground instrumentation platforms allow measurement of all surface and airborne targets. Weapon system performance data and target signatures are used to develop/validate digital and hardware-in-the-loop (HWIL) models for virtual missile-to-target engagements, etc.

Open-air assets include the Missile Warning Sensor Stimulator, Seeker Test Van, Signature Test and Evaluation Facility (with a 300-ft tower and rail-based target movement and rotating platform), missile plume simulators, Advanced MMW Imaging Radar System Rail-Synthetic Aperture Radar, MMW Obscurant Characterization System, Lynx: Ku-Band Synthetic Aperture Radar, Mobile Radiometric Instrumentation Tower System, and three flight certified pod-based platforms (the Beam Approach Seeker Evaluation System [BASES], the Calibrated IR/visible/UV Ground and Airborne Radiometric Spectrometer [CIGARS], and the Supersonic Airborne Tri-Gimbal Infrared System [SATIRS]). Finally, the Eglin Mobile Missile Launcher System completes the end-to-end test capability, providing live launch capability for man-portable air-defense systems against real or simulated aircraft. ■

SATIRS on F-15E.

AIRCRAFT ENGINE

EXHAUST PLUME PHENOMENOLOGY MODELING IMPROVEMENTS FOR BETTER HITL SCENE GENERATION & MISSILE ENDGAME PERFORMANCE

By Scott E. Armistead and Thomas Mizer

BACKGROUND

Various Department of Defense (DoD) modeling and simulation (M&S) groups perform digital and hardware-in-the-loop (HITL) threat missile flyout and hit point analyses to assess weapon effectiveness and platform susceptibility (and ultimately survivability) based on signature models derived using either organically developed tools and processes or those available from other government, industry, or academic sources.[1] However, many of the contemporary

government tools for prediction of aircraft engine exhaust signatures were developed when lack of processing power and similar reasons required the developers to use simplified lower-fidelity methodologies to achieve solutions in a reasonable time. Such is the case with the original F-16C engine exhaust plume signature model, a simplified variant of the original missile-oriented Standard Plume Flowfield (SPF)[2] code. The SPF code was incorporated into the Spectral and In-band Radiometric Imaging of Targets and Scenes (SPIRITS)[3] signature generation code to provide the aircraft plume mixing between a principal core exhaust and the surrounding freestream in support of infrared (IR) signature predictions. While this approach was reasonably suited for the plume modeling of B-52 turbojets within a limited range of flight conditions, its predictive limitations for other aircraft systems became increasingly apparent in the early 1990s as the importance of internal turbofan augmentor/nozzle mixing and downstream shock trains on plume IR signature accuracy was recognized. When attempting to extend these models to rotorcraft, the application is even more limited, especially given the earlier codes' basis on isolated, round nozzle configurations with legacy engine exhaust thermal barrier coatings of consistent, highly diffuse, and high-emissivity behavior.

Historically, the use of these tools can lead to poor predictions of plume spatial and radiometric characteristics as well as plume impingement heating on aircraft surfaces when performed for higher angles of attack or for airframe designs that include advanced exhaust system configurations (e.g., rectangular nozzle geometries, serpentine exhaust paths, highly integrated engine-airframe installations, and efficient plume mixing enhancement devices). This fact, in turn, impacts the ability to properly generate scene and signal information to support both digital and HITL modeling and performance assessment of various electro-optical/infrared (EO/IR) sensors and associated systems, such as weapon seekers, guidance and navigation control loops, missile warning systems, countermeasure/counter-countermeasure (CM/CCM) systems, etc. These issues are exacerbated as sensor technologies evolve and take advantage of improvements in resolution, sensitivity, and imaging capabilities. Models that can more fundamentally address these nonaxisymmetric, high-aspect ratio geometries, along with their inherently more complex mixing physics, within reasonable computational timeframes and that can be integrated into the existing M&S process would certainly lead to more reliable predictive capabilities, development of better flow path configurations, and improved weapon effectiveness and platform survivability assessments.

> IR and RF signature model development is a key component to fully support future missile and sensor programs

Attempts to improve aircraft plume modeling capability using more advanced Navier-Stokes flow solvers, however, were initially hindered by difficulties in their operational usage and long solution runtimes; these factors limiting their acceptance by the modeling community in favor of quick-fix, ad hoc approximations to correct observed signature prediction deficiencies, which usually result in other issues such as poorer correlation of spectral data. Fortunately, advancements in modern computer hardware technology, along with development of improved flow algorithms, have enabled the development of fast-running and highly accurate heat transfer and computational fluid dynamics solvers that can support the IR signature M&S requirements needed to support modern weapon system assessments.

With this in mind, the Guided Weapons Evaluation Facility (GWEF)[4] in collaboration with the QF-16 System Program Office (SPO),[5] both located at Eglin AFB, FL, and supported by the SURVICE Engineering Company[6] and Combustion Research And Flow Technology (CRAFT Tech)[7]—have undertaken an initiative to improve both fixed-wing and rotary-wing aircraft exhaust plume signature modeling in terms of fidelity and spectral/spatial characteristics and integrate the developed code and methodologies into accepted DoD aircraft signature and scene generation tools. The initial programs/platforms selected for development and validation of the M&S tools and processes through incorporation during their assessments were the QF-16 (fixed-wing) and UH-60M[8] (rotary-wing) (Figure 1).

The QF-16 program was a relatively new start program at the GWEF. That, along with the requirement to model three engine variants (the F100-PW-200D, F100-PW-220E, and F110-GE-100B) and a robust ground and flight test data collection program, allowed fidelity studies to be performed on the impact of various mixing devices within the flow path. Development and verification of the QF-16 model also took advantage of the latest FLIR™ state-of-the-art electrically cooled MWIR and LWIR imaging sensors, as well as the first field-usable hyperspectral imager manufactured by Telops™ for collection of ground and in-flight data for model correlation and verification. This spectral imaging capability, owned by the 782 TS/RNWI Instrumentation Branch at Eglin AFB, FL,[9] provides the ability to verify and validate (V&V) models to measurements quickly and accurately since the target can be seen spectrally without any assumptions to boresighting setup. Additionally, since spectral information for each individual pixel of the image is collected, each image can be separated into distinct frequencies as well as composited across a user-specified bandwidth using image/spectral processing tools developed by RNWI. The hyperspectral imager has been integrated into RNWI's post-processing methodology using the standard FLIR SAF file format, which provides data product end-users a self-extracting data and tool product. This product is a significant benefit, especially in DoD classified processing environments, where getting approval for the installation of unapproved software can be a rigorous process.

Figure 1: QF-16 Exhaust Nozzle (top [2014© William Schenck]) and UH-60M with UES Aft of Main Rotor Hub (bottom).

The UH-60M program, on the other hand, was an effort already under way that afforded an opportunity to assess the efficacy of merging advanced commercial modeling techniques into a typical DoD production model development cycle (with respect to data analysis and correlation, cost, schedule, etc.), where model verification could be performed against tried-and-true dewar-cooled single-band MWIR sensor data that had already been collected and verified by both the Government and the engine original equipment manufacturer (OEM). The UH-60M, configured with the T700-GE-701D engine, is particularly challenging due to the dual upturned exhaust system (UES) and exhaust mixing with the main rotor downwash. However, this system is not atypical of exhaust signature suppression techniques that could be expected to be employed on current and future rotorcraft platforms.

More succinctly, the primary difference in the paths taken with the two programs is that the QF-16 effort required new analytical processes and codes as well as measurement process advancements related to fixing issues with DoD legacy models, whereas the UH-60M effort had access to multiple high-quality existing datasets, allowing modeling issues to be addressed largely with advanced COTS codes.

M&S PROCESS IMPROVEMENT

As part of the QF-16 SPO's efforts to field the next-generation air superiority target, IR and RF signature model development is a key component to fully support future missile and sensor programs. As such, they conducted numerous meetings and discussions with the GWEF, engine OEM aerothermal analysis subject-matter experts (SMEs), and industry personnel with expertise in the development of both proprietary and DoD aircraft hot parts and exhaust plume signature codes. The conclusion was that better modeling methodologies and tools would be needed to address the aforementioned issues and their specific requirements to ensure the capability to support current advanced and future weapon systems.

In that context, efforts were sponsored to improve QF-16 IR signature M&S, leading to improvements in the target scene inputs feeding digital and HITL simulations for the assessment of CM and weapon system effectiveness. The implementation of these efforts improves predictive results for all phases of the weapon engagement process, from search and acquisition to tracking throughout flyout to endgame response and hitpoint assessment. Key to this is the ability to create a relatively fast, but highly accurate, flowfield with three-dimensional effects of swirl and multi-stream mixing phenomena, as well as nozzle internal geometry effects. In other words, a large range of realistic nozzle characteristics would need to be simulated. Typically, this level of simulation is not performed in DoD M&S; it is usually performed only at the OEM level during the design and manufacturing process using codes normally not available to the DoD. (And, even if these simulations were run, they would generally not be suitable for use during the normal acquisition process due to the long run times.) Moreover, the process would have to be workable within the framework of the current M&S process (as shown in Figure 2) (with the modern modifications to the process shown within the dotted lines), while keeping in mind the need to simultaneously reduce the time and cost normally associated with the process.

The typical signature process begins with standard engine cycle deck output parameters and use of tools such as TRBEXT (a module within SPIRITS) to describe the core gas flow stream (mass flow rate, pressure, and temperature), as well as fuel consumption rate for use as boundary conditions in a subsequent flowfield generation code. Exhaust species compositions are usually based on a complete combustion assumption and a uniform exhaust exit profile, which is not generally the case. For hot parts, exhaust component temperatures, which are directly related to the exhaust flow, must be calculated. This calculation requires an understanding of the film cooling effectiveness metric, which is dependent on the various cooling methods employed (usually either slots or cooling holes). The metric is generally known only to the engine manufacturer. To overcome this, various methods have been used to approximate these hot part temperatures; however, they still have insufficient accuracy and require the analyst to make considerable assumptions and rely heavily on measured data, which may not be available, for correlation and corrections. In the UH-60M modeling process, conjugate heat transfer with the computational fluid dynamics (CFD) solution based on advanced commercial codes could be used as a starting point, and final adjustments could be made by the aerothermal analyst through verification of the model to the available measured data.

A problem arises in that this particular methodology can be stressed when developing models that employ engineered cooling flow features using an active method to draw cooling air from the engine cycle for use in reducing the temperature of hot parts in the exhaust flow path, as is the case with the F-16. This can be addressed by inserting thermocouples into exhaust system hot parts to collect temperature data within the field-of-view of the measurement sensing equipment and application of a general understanding of the reflective properties of the hot part surfaces to determine actual hot part metal temperatures vs. apparent temperatures. This method is used regularly by both the airframe and

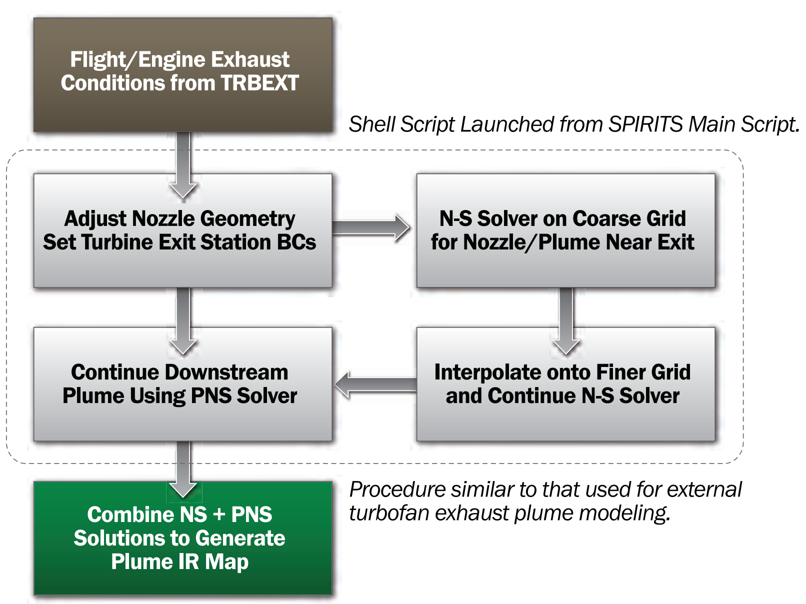


Figure 2: Insertion of High-Fidelity QF-16 Plume Modeling Methodology into Legacy DoD Process.

engine OEMs and has been incorporated into the QF-16 modeling process by installing thermocouples, with assistance from the engine OEM, in one of the divergent seal segments of the variable geometry exhaust nozzle and measuring the bidirectional reflectance distribution function (BRDF) of the coating on the exhaust nozzle segments) using a Surface Optics SOC-400 field portable reflectometer provided by RNWI.

Once the necessary data were in hand, fundamental research was needed to develop a SPIRITS fast running plume solver module that could provide highly accurate results for the various engine flow path configurations across the necessary flight conditions. The inclusion of a true Navier-Stokes methodology in the critical first several meters (user adjustable) of the plume—combined with a faster, although less accurate, parabolized Navier-Stokes method on the less critical (less hot) sections of the plume—worked very well. The QF-16 program succeeded in that CRAFT Tech and SURVICE were able to create a relatively fast (for CFD) high-fidelity flowfield model that far surpassed the prior DoD model in realism (as verified through correlation to both ground and flight test data). Features of the new SPIRITS F-16 plume module include direct modeling of the internal core/fan mixing starting at the turbine exit, incorporation of afterburning effects, the ability to handle incomplete combustion, shock-diamond and Mach disc capturing, and improved turbulence modeling for high-speed conditions. Moreover, this new plume solver exists as a seamless replacement within the SPIRITS framework without requiring additional user intervention or specialized flow modeling expertise. With today's multi-core laptops and desktops, these simulations, previously requiring 1 day of dedicated computational effort on a supercomputer, now require less than 1 minute while simultaneously providing improved predictive accuracy.

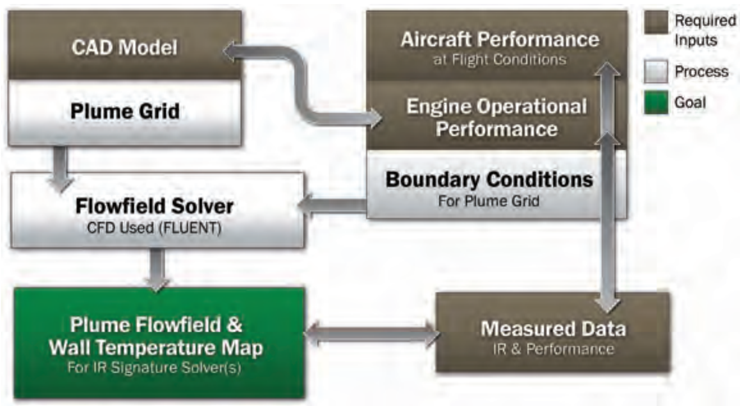


Figure 3: Generic CFD-Based Process as Used in H-60M Plume Modeling.

For UH-60M, the method was laid out into the most generic of processes for solving a high-fidelity flowfield. This action was performed to both simplify and provide future extensibility to any available CFD solver. The process is shown in Figure 2.

> The initiative will provide fundamental improvements to the assessment of advanced platforms, such as the Joint Strike Fighter...

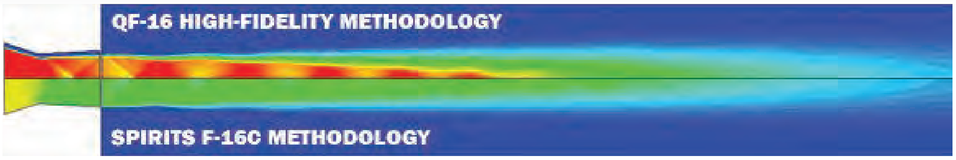
The methodology in Figure 3 is essentially academic in that the IR model development goal is all about the flowfield. How the analyst gets there is essentially the same for a CFD model: develop the geometry, build the grid, apply boundary conditions from a GFE or OEM engine cycle deck, shove the inputs into a CFD solver code, and then verify the outputs against measured data.

RESULTS

For the QF-16, the correct modeling of shocks from a fighter engine's typically under-expanded nozzle setting was important to the program's direction of improving fidelity. Figures 4 and 5 provide a few examples of the program's success in incorporation of complex flow path element modeling and accurately predicting plume phenomenology using both of the methodologies discussed previously.

Further, when compared to in-flight test data, the model is providing both the appropriate plume intensities along with correct shock diamond spatial characteristics, as shown in Figure 6.

The QF-16 model is currently undergoing extensive V&V as newer data collection instrumentation provides



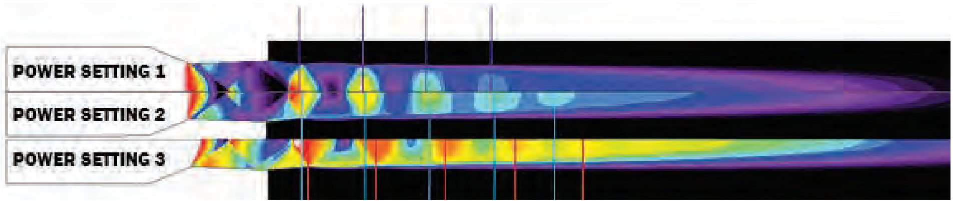


Figure 4 (top): Comparison of Flowfields as Generated by Legacy Process and Modified Legacy Process.
Figure 5 (bottom): Generic H-60M Process Used to Determine QF-16 Shock Diamond Centroid Locations Across Three Power Settings.

plume imagery/radiometric data with several orders of magnitude better resolution using field-capable hyperspectral imagers. In the case of the QF-16 data collection led by the 782nd Test Squadron at Eglin AFB, FL, a Telops hyperspectral imager is being used in lieu of the typically boresighted Bomem spectrometer. Additionally, hot part definition and temperature prediction are more accurately captured with higher-resolution filtered imagery correlated with remotely acquired data using nozzle wall thermocouples, allowing for high-fidelity temperature mapping.

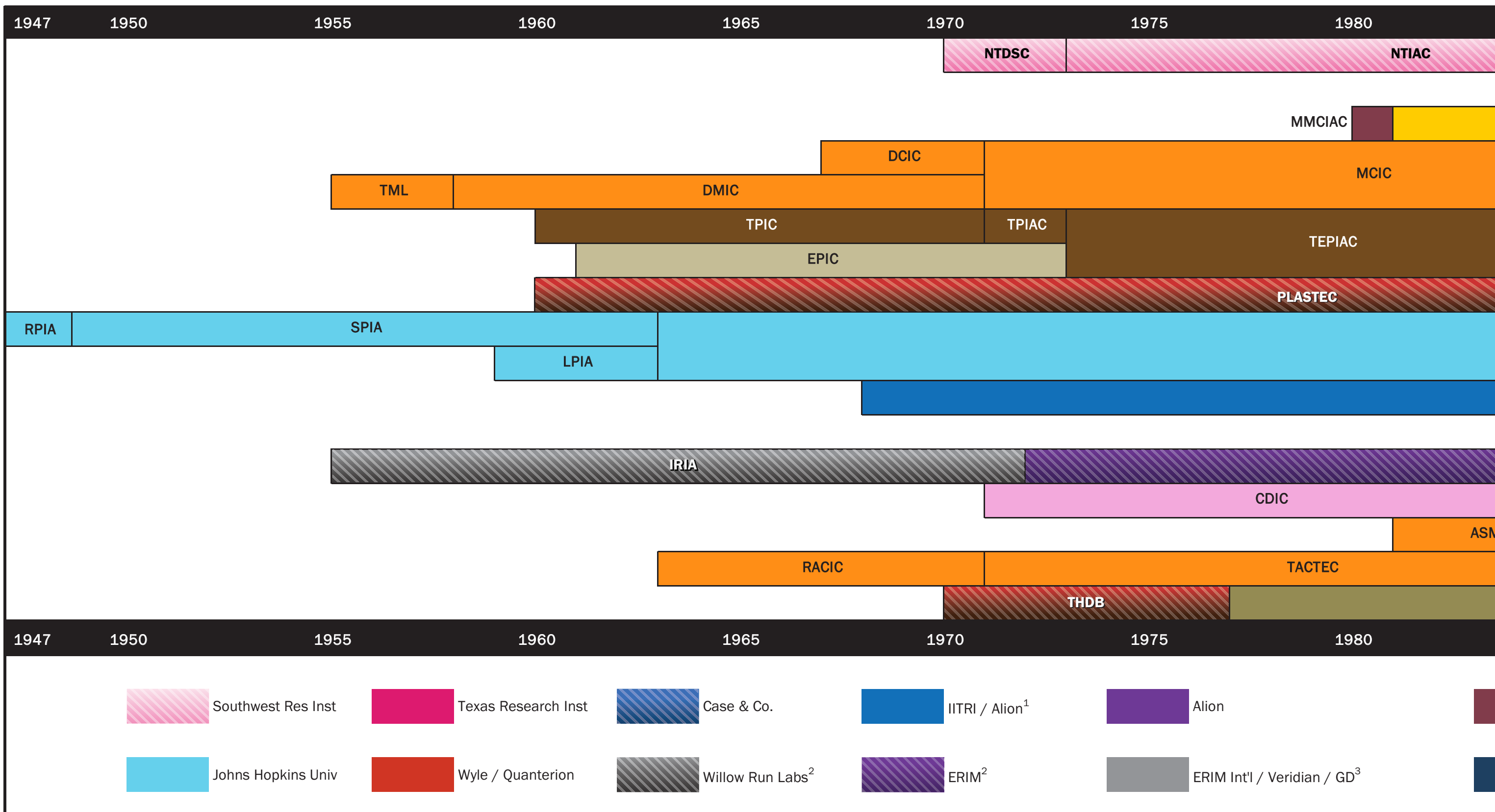
The QF-16 M&S program tasks are also unique in that project limitations will result in no in-flight measurements of the F100-PW200D-powered aircraft. The last test, a ground test for the F100-PW-200D engine, is scheduled for completion in latter 2014, with the data correlations to be performed shortly afterward. Signature in-flight IR performance for that engine variant model will be extrapolated from the ground test measurements of all three engine variants and in-flight measurements for the other two engine variants. The impact of this limitation is minimal, as data taken so far show each variant's IR performance is consistent with what its respective GFE engine cycle decks, providing confidence that extrapolation to the F100-PW-200D will be a straightforward process.

UH-60M plume development is a similar model in that there is a need for a high-fidelity solution that provides both spatial and radiant intensity correctness. Overlaid onto this requirement were the typical program production-oriented tight constraints on both cost and schedule. In particular, the schedule constraints required that the work be completed in a matter of several weeks vs. the normal process that usually takes many months. Auto-meshing techniques were initially employed that kicked off the needed scene generation object, and the COTS CFD solver, ANSYS Fluent™, was employed to quickly arrive at a workable solution that generally matched the measured data from the dewar-cooled MWIR sensing instrumentation used by the Navy to collect imagery and radiometric data. In this manner, a plume solution was developed and the same CFD solution set was used to generate wall temperatures from the built-in conjugate heat transfer solver within Fluent™. It should be noted that this method of creating the flowfield and acquiring metal wall temperatures is entirely an academic process. Fluent™ was chosen due to the solver's tight integration with the standard ANSYS™ meshing utility, the numerous available turbulence models, species tracking abilities, and built-in heat transfer analysis capabilities. Additionally, the entire CFD process can be parameterized within the ANSYS Workbench™ environment, yet the output can remain ASCII generic, thus allowing any CFD process to be used.

Figure 6: Measurement Sesnor Image Compared to High-Fidelity QF-16 Modeling Process Output.

An important aspect to this process, often encountered in V&V of IR models

1946—2014 THE DEFENSE SYSTEMS ANALYSIS CENTER HERI

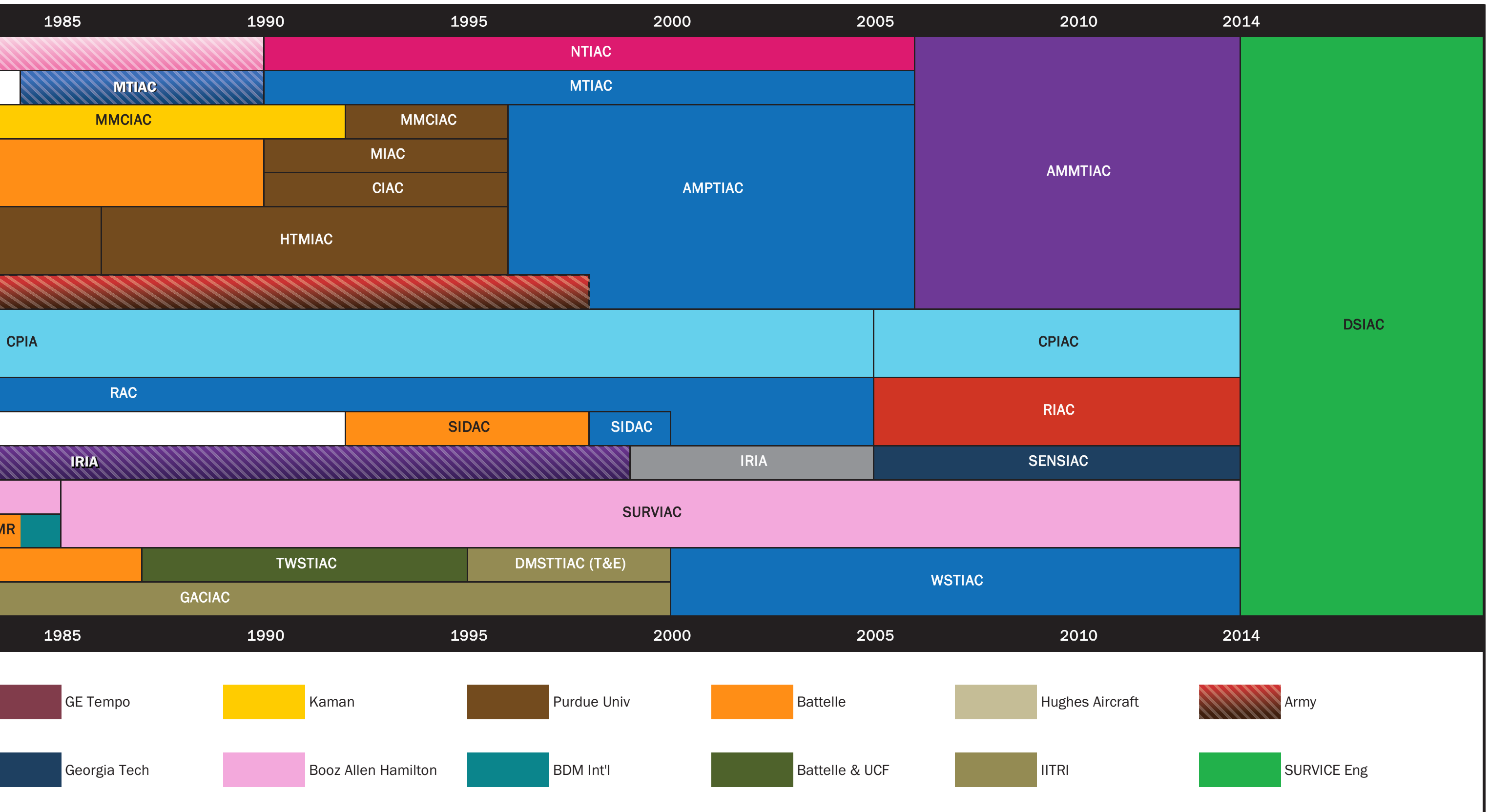


[1]Alion was formed by IITRI employees in December 2002. [2]Willow Run Laboratories formally separated from the University of Michigan in 1972, becoming Environmental Research Institute of Michigan

AMMTIAC	Advanced Materials, Manufacturing & Testing Information Analysis Center
AMPTIAC	Advanced Materials and Processes Technology Information Analysis Center
ASMR	Aircraft Survivability Model Repository
CDIC	Combat Data Incident Center
CIAC	Ceramics Information Analysis Center
CPIA	Chemical Propulsion Information Agency
CPIAC	Chemical Propulsion Information Analysis Center
DCIC	Defense Ceramics Information Center
DMIC	Defense Metals Information Center
DMSTTIAC	Defense Modeling, Simulation & Tactical Technology Information Analysis Center
DSIAC	Defense Systems Information Analysis Center
EPIC	Electronic Properties Information Center
GACIAC	Guidance and Control Information Analysis Center
HTMIAC	High Temperature Materials Information Analysis Center
IRIA	InfraRed Information Anal
LPIA	Liquid Propellant Informat
MCIC	Metals and Ceramics Infor
MIAC	Metals Information Analys
MMCIAC	Metal Matrix Composites I
MTIAC	Manufacturing Technolog
NTDSC	Nondestructive Testing Da
NTIAC	Nondestructive Testing Inf
PLASTEC	Plastics Technical Evaluat
RAC	Reliability Analysis Center
RACIC	Remote Area Conflict Infor
RIAC	Reliability Information Ana
RPIA	Rocket Propellant Informa

INFORMATION
TAGE

The long and rich history of the Department of Defense Information Analysis Centers began with the establishment of the progenitor Rocket Propellant Information Agency (RPIA) in December 1946. The DSIAC lineage includes 40 distinct predecessor organizations that have supported the greater DoD community for more than a half century.



(ERIM). [3]ERIM International subsidiary established in 1997; purchased by Veridian in 1999; Veridian bought by GD in 2003.

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SENSIAC	Military Sensing Information Analysis Center
SIDAC	Supportability Investment Decision Analysis Center (1992-1998)
SIDAC	Supportability Information and Decision Analysis Center (1998-2000)
SPIA	Solid Propellant Information Agency
SURVIAC	Survivability & Vulnerability Information Analysis Center
TACTEC	Tactical Technology Center
TEPIAC	Thermophysical and Electronic Properties Information Analysis Center
THDB	Terminal Homing Data Bank
TML	Titanium Metallurgical Laboratory
TPIAC	Thermophysical Properties Information Analysis Center
TPIC	Thermophysical Properties Information Center
TWSTIAC	Tactical Warfare Simulation and Technology Information Analysis Center
WSTIAC	Weapon Systems Technology Information Analysis Center

to sensor data, is determining the correctness of the IR contributors; and this problem is generally prolific from the bright exhaust cavity, since as exhaust systems become more complex in their flowpaths, cooling, and materials, the ability to quickly determine the breakout of the major contributors becomes increasingly difficult, often requiring experienced IR analysts to methodically determine and correct problem areas of the IR model. Although HITL time constraints prevented implementation for this particular effort, a CFD grid of the full model as provided was developed to accurately simulate and determine system aspects that would affect signature radiometric values. This is academically depicted in Figure 7 using Flow Vector and Temperature solution output for a notional exhaust system. Thorough modeling is necessary to provide both the realism and accuracy needed to adequately assess modern weapon systems performance within the HITL simulation process. The initial coarse model, as used in this HITL effort, had a mostly isothermal cavity and thus required some fine tuning of the signature values in this area. And in time-honored IR analyst tradition, "assumptions were made" based on comparing the model to the measured data. However, care must be taken as erroneous assumptions can lead to poor results in other areas, such as skewed spectral output. Using a higher-fidelity solution was shown to provide good correlation to the measured data, reducing the need to manipulate model outputs. Here again, we illustrate the solution output in Figure 8 using the simplified mixer-ejector exhaust system. For

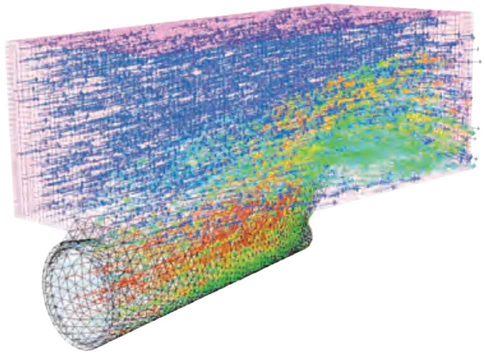


Figure 7: Flow Velocity Vectors and Temperature Visualized on Top of a Predominately Auto-Generated Mesh.

example, consider the case where spectral data are either incorrect or unavailable; a model that allows accurate simulation of the hot parts temperatures will be more accurate spectrally. This methodology will be implemented for future efforts.

By capturing all propulsion integration and system features for the system, not only did the developed model more closely match known propulsion requirements, but a clearer understanding of the relative magnitudes of the various energy sources within the HITL scene was produced.

CONCLUSION

Both the QF-16 and UH-60M programs successfully developed improved plume signature models that showed good correlation to their respective test data and demonstrated the viability of incorporating the methodologies into the model development process to improve model quality.

The impact of these two modeling processes is incremental and yet profound. Under QF-16, the legacy DoD IR signature modeling process was modified to provide high-fidelity CFD modeling as a seamless option to support exhaust plume modeling, with the impact to the model end user being transparent. UH-60M, on the other hand, bypasses and integrates several of the more time-consuming legacy methods, using commercial-off-the-shelf (COTS) tools in their place. While requiring some extra intervention on the part of the user, the use of COTS CFD and heat transfer solution methods was performed in a proprietary-less implementation, providing for future extensibility to other codes. More importantly, from a production perspective, this new modeling process provides the GWEF a capability to model target exhaust plumes and calculate hot part temperatures

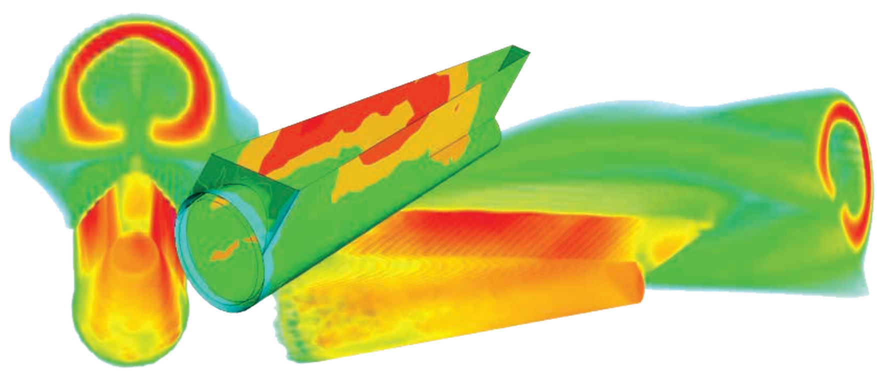


Figure 8: CFD Based Flow and Wall Temperature Mapping for a Notional Turboshaft Mixer-Ejector Exhaust System.

at a level equivalent to many OEM specialized codes, with the only possible shortcoming being the availability of input data, such as geometry, cycle deck, and other proprietary data to which the Government may not have access. However, just as proprietary data availability is problematic to the point of routine, the "routine" availability of quality IR measured data is more common and can bypass some of the need for proprietary data, allowing this type of process to succeed within the DoD, where, ironically, it might fail if relied upon in industry. Additionally (and from a business perspective, probably more importantly), this new process allows the GWEF to take better advantage of organic data collection capabilities within the sister 782nd Seekers and Sensors Test Flight and in-house modeling processes to develop high-fidelity models significantly quicker than the lower-fidelity models of the past.

Both programs are still undergoing assessments at the GWEF to determine the impacts to weapon effectiveness and platform susceptibility. It is anticipated that the initiative will provide fundamental improvements to the assessment of advanced platforms, such as the Joint Strike Fighter, in terms of cost and schedule savings and improved data quality. ■

BIOGRAPHIES

SCOTT ARMISTEAD is a DSIAC senior staff engineer as well as the SURVICE Engineering Company's Technical Operations Lead for its Gulf Coast Area Operations. He is responsible for SURVICE's modeling, simulation, analysis, and computer engineering support to the 782nd Test Squadron Guided Weapons Evaluation Facility (GWEF) and Joint Technical Coordinating Group Joint Munitions Effectiveness Manuals (JMEM) programs at Eglin AFB, FL, and support to the Air Force Test and Evaluation (AF/TE) organization in Washington, DC. Mr. Armistead has more than 27 years of experience supporting DT&E, OT&E, and LTF&E for Air Force, Army, and Joint Service programs in the areas of IR, visible, UV, millimeter wave, seismic, magnetic, and acoustic sensors and weapons technologies; weapon systems effectiveness; countermeasures development; and platform susceptibility. He has served as the Chief Engineer for the JASSM and SDB Combined Test Flight, Lead Susceptibility Engineer for the Air Force Live Fire Office, Technical Advisor for the 96th Test Wing EO/IR and MMW Systems Test Flight, and Test Manager for the Joint Munitions Program Office. He graduated from the University of Florida in 1986 with a B.S. in Nuclear Engineering.

THOMAS MIZER is a senior engineer and IR systems analyst for the SURVICE Engineering Company. He has 15 years experience in propulsion aerothermodynamics and 11 years in electronics equipment and instrumentation production. He has a strong propulsion exhaust systems background with foundations in low observables exhaust systems, preliminary exhaust aerothermal design, signature and performance analysis, model and prototype build, instrumentation, and testing in both laboratory and field measurements environments. Mr. Mizer has worked for Pratt & Whitney Large Military Engines Signatures Discipline Group and Rolls-Royce North American Technologies Liberty Works, where he performed aerothermal design, analysis, and test of subsonic ejector exhaust systems for low observable (LO) aircraft installations. He is currently a Senior Engineer at SURVICE Engineering where he performs IR susceptibility analysis from signature creation to missile flyout modeling, including complete airframe and propulsion system modeling and plume and aerothermal modeling. He is currently supporting the 782nd Test Squadron GWEF hardware-in-the-loop Scene Generation and Sensors & Seekers groups in model development and validation using measured data, with a primary focus on CFD plume flowfield generation and conjugate heat transfer prediction of exhaust system hot parts. Mr. Mizer graduated from the University of Florida in 1998 with a Bachelors of Science degree in Mechanical Engineering.

REFERENCES

1 Additional information on radiation theory and sources, aircraft IR signature simulation, and EO/IR data collection can be found in the SENSIAC Handbooks Infrared Handbook, Infrared & Electro-Optical Systems Handbook Set, Sources of Radiation, and the SENSIAC SOAR Infrared Signature Simulation of Military Targets.

2 SPF-III is a US Government-owned Joint-Army-Navy-NASA-Air Force (JANNAF) computer code used for predicting the gas dynamic structure of single- and two-phase low altitude (<70 km) rocket exhaust plumes and is used to predict plume signatures and plume/vehicle interaction phenomena. SPF-III distribution is provided by The Johns Hopkins University Chemical Propulsion Information Analysis Center (JHU CPIAC), Columbia, MD, cpiac@cpiac.jhu.edu, 410.992.7300. Visit https://www.cpiac.jhu.edu/node/20 for more information.

3 SPIRITS is a U.S. Government-owned JANNAF integrated system of computer codes to predict EO (UV, visible, and IR) spectral and spatial data for aircraft hardbody and plumes. SPIRITS distribution is provided by the JHU CPIAC, Columbia, MD, cpiac@cpiac.jhu.edu, 410.992.7300, with release approval from the 782 TS/RNWGH (GWEF), Eglin AFB, FL, Ms. Amenda Amick, mary.amick@us.af.mil, 850.882.9978. Visit https://www.cpiac.jhu.edu/node/20 for more information.

4 The GWEF, Eglin AFB, FL, is the DoD's premier full-spectrum (UV, IR, visible, laser, MMW, traditional RF, and inertial/GPS) digital M&S and HITL test facility for weapons parametric measurements, CM/CCM testing and performance characterization. For more information, contact Mr. Visal Som, 782 TS/RNWGH, visal.som@us.af.mil, 850.882.9978.

5 The QF-16 Program Office, Eglin, AFB, FL, is currently performing systems integration and testing of the F-16 as the newest aircraft to assume the unmanned Air Superiority Target role for the DoD. For more information, contact Mr. Clayton Vind, AFLCMC/EBYA, clayton.vind.2@us.af.mil, 850.883.3368.

6 The SURVICE Engineering Company provides services in the areas of systems engineering, M&S, test and evaluation, analysis, metrology, and applied technology solutions. For more information, contact Mr. Scott Armistead, scott.armistead@survice.com, 850.362.6920.

7 CRAFT Tech specializes in high-fidelity CFD simulation of complex flow and combustion problems. For more information, contact Mr. Neeraj Sinha, sinha@craft-tech.com, 215.766.1520.

8 The UH-60M is an upgraded derivative of the UH-60 helicopter featuring improved payload, digital cockpit displays, strengthened fuselage, composite spar wide-chord blades, and more powerful engines (T700-GW-701D). For more information, Mr. Keith Hilliard,256.842.4436/256.541.1775 (bb).

9 The 782nd Seekers and Sensors Test Flight provides instrumentation development and data collection and analysis support activities, for DoD T&E activities including both red and blue missile performance, aircraft self-protection systems, and threat system performance in support of aircraft and surface target survivability studies. The Test Flight's extensive target signature measurement capability provides calibrated broadband, spectral, and hyperspectral data across the full electromagnetic spectrum in operational environments. For more information, contact Mr. Rusty Bauldree, Chief, 782 TS/RNWI, 850.882.5602, russel.bauldree@us.af.mil.

EFFECT OF MISSILE LAUNCH AZIMUTH

ON THE MAGNITUDE OF SIMULATED POINT-OF-CLOSEST-APPROACH MISS DISTANCES TO LARGE AIRCRAFT SYSTEMS

By Robert Yelverton, Jr.

ABSTRACT

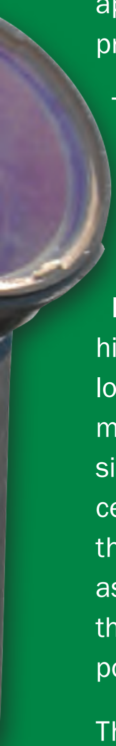
Using selected principles in design of experiments, the researcher conducted a simulation-based missile hit-point study that explored the conventional practicality of a typical survivability investigation. The relationship of aircraft susceptibility to missile attack is a well understood function of one or more missile launch parameters. Specifically, the researcher explored the statistical relationship between the missile's launch azimuth and the resultant variations in the magnitude of

U.S. Army PFC Trevor Gaston, with the 2nd Battalion, 263rd Air Defense Artillery Regiment, demonstrates an FIM-92 Stinger man-portable surface-to-air missile system at Bolling Air Force Base.

point-of-closest-approach (PCA)miss distances to the aircraft.

INTRODUCTION

The development of an effective evaluation method that addresses the survivability issues of concern for a large aircraft system under study within available fiscal resources and practical bounds was required. The researcher believed the most effective domain to achieve this objective was through the use of modeling and simulation (M&S) and applied design of experiments (DOE) principles/methods.



The experiment had two objectives. First, establish a susceptibility baseline for an unprotected commercial-derivative large aircraft against a typical ground-launched missile threat using highly specialized hardware-in-the-loop (HITL) simulation and aircraft modeling techniques. Second, use simulation-generated hit-point concentrations (susceptibility) to narrow the scope of follow-on vulnerability assessments to areas on the aircraft that have the highest vulnerability potential.

The overarching purpose of the study was to relate specific launch parameter groupings and resultant concentrations of hit-points with specific areas of the aircraft. If a relationship existed, the strength of that relationship was used to suggest a basis for prioritizing where and to what extent follow-on susceptibility and vulnerability investigations were conducted. However, the researcher's ulterior purpose was to use this study as an opportunity to apply DOE methods in an attempt to document potential improvements to an older, less efficient process.

Experiments of this nature can involve an infinite number of parametric permutations and replicates. The researcher chose to limit the missile launch parameters to doctrinally sound distributions of launch range, elevation, and azimuth about the target aircraft. Also, the aircraft flight regimes were limited to nominal airspeeds and altitudes indicative of take-offs and landings. Although excursions combining launch and flight parameters that resulted in extraordinary engagements were examined in this study for completeness, they were not considered here.

Hypothesis

Research in the area of HITL modeled or simulated aircraft/threat interactions is highly specialized and on the forefront of advancing the science of modern aircraft survivability evaluation. Accordingly, virtually no specific literature on this topic exists, which prevented the ability to formulate a hypothesis based on a literature review. However, the researcher's direct association with many projects related to this research topic allowed the development of a hypothesis based on years of personal experience and first-hand knowledge of deficiencies in aircraft survivability investigative methodologies.

The researcher believed combinations of independent missile launch and aircraft flight regime variables may have a statistically significant influence on the end-game outcome represented by several dependent variables. Studying the launch azimuth's influence on the resultant magnitude of the PCA miss-distance posed a particularly interesting and powerful relationship. While this test represents only a single interaction of many possible interactions, it serves two intertwined purposes. That is, it tests that a statistically significant relationship does (or does not) exist, between missile launch parameters and a target aircraft.

As such, the researcher submits that the missile's launch azimuth results in a statistically significant difference in the magnitude of the PCA miss-distance (hypothesis). Alternatively, the missile's launch azimuth does not result in a statistically significant difference in the magnitude of the PCA miss-distance (null-hypothesis).

RESEARCH METHODS

Research Design

This descriptive study was conducted at the Guided Missile Evaluation Facility located at Eglin AFB, FL. The end-game outcomes of HITL simulations of doctrinally typical missile engagements against a modeled commercial-derivative class aircraft were evaluated. The outcomes were expressed in terms of missile PCA distances to the missile seeker's track-point as a function of varied launch parameters (i.e., azimuth, elevation angle, and range to target).

The missile-to-target engagement matrix for this study was vast, and a comprehensive discussion of its results would have been both interesting and revealing, but not consistent with current classification guidelines. Instead, the researcher devised a method of aggregating the experimental input factors/levels as well as the resultant output responses in a manner that tested the hypothesis without implying the susceptibilities and/or vulnerabilities of a specific aircraft-threat interaction.

Research Model

This study was based on experimentally modeled and simulated missile engagements against a commercial-derivative aircraft. Descriptive and inferential statistics were applied to each of six sample groups used to summarize the data. Significance was tested by performing a parametric analysis of the variation (ANOVA) between the resultant PCA miss distances in each group. The magnitude in variation was used to test the hypothesized influence of the combinations of independent missile launch parameters on the dependent PCA miss-distance outcome. All analysis was performed with the aid of the Statistica™ software package.

Sources of Data

For each simulated missile engagement, there were two data source categories: pre-determined input data and resultant output data.

The predetermined input data consisted of the beginning state data for the missile engagement scenario. The input data comprised the missile type, missile launch parameters (range, elevation, and azimuth to the target), and the target aircraft state (take-off/landing, altitude, and airspeed).

As the experimental engagement executed, resultant output data were collected. The primary output data consisted of PCA distance to the target or a distribution of hit-points on the target aircraft. These output data supported (or did not support) the relationship between the beginning state launch parameters and specific targeted locations on the target aircraft based on concentrations of hit-points.

Forensic output data from the missile guidance module were collected. These data, which provided a phenomenological basis for a given missile trajectory that led to a miss or hit, included component velocity vectors, angle-of-attack, yaw, pitch, and roll.

RESULTS

Table 1 contains all of the simulated PCA miss-distance data points used

Table 1: Minimum PCA Miss Distances for All Missile Launch Elevations and Ranges

Minimum PCA Miss Distance (All Elevations and Ranges)						
Take-Off				Landing		
Nose	Beam	Tail		Nose	Beam	Tail
4.16270	3.01850	0.88181		3.11490	1.21960	0.93218
3.69140	1.90110	0.63007		4.00580	1.60030	1.19680
4.50270	3.87370	1.33360		3.05870	2.90620	1.35210
5.98830	0.53953	1.04670		2.12920	2.76980	0.91673
5.46900	0.68031	1.03410		3.83330	2.30770	1.75070
5.47860	4.12850	1.00590		3.51370	2.25950	1.61610
8.03190	2.23970	0.05841		1.07950	1.00370	0.70954
5.94380	3.96640	0.64044		1.23610	1.92480	1.19240
8.15030	4.59070	1.22090		2.43630	2.91240	1.05040
4.84800	5.31210	1.07150		2.53710	1.21780	0.42839
6.60410	1.46140	0.66422		0.81787	1.42500	0.55169
5.60030	3.91750	0.98527		1.15170	2.01100	0.48412
1.20780	5.25190	1.36800		1.76840	0.59498	1.07190
0.47520	10.16430	1.57580		0.78415	1.03400	0.97170
0.71456	7.17390	1.12260		1.47450	0.59137	1.38740
1.31010	6.07440	1.43850		1.29710	1.21000	1.65450
0.13549	11.36810	0.94782		0.72409	1.40330	1.84240
1.38010	6.87260	1.62100		2.16890	1.84260	2.92330
1.31740	5.05620	0.92419		2.70370	1.02230	1.40400
1.48550	3.91350	1.07670		0.53166	1.22980	0.87233
0.35331	1.71410	1.30880		2.10760	0.99266	0.97832
1.66670	5.66770	0.79713		8.86230	0.33405	0.87594
1.41340	4.72500	2.72630		1.69240	1.32400	0.63682
0.67842	5.70320	1.96070		0.79844	1.11790	0.27324
4.91420	1.52340	0.59818		0.75686	3.17170	0.20338
4.36280	2.42260	0.85379		1.01250	2.51390	0.40944
4.06790	4.15220	1.11780		3.02200	5.46980	0.41617
6.52870	0.73006	0.86805		0.49533	1.93890	0.49160
5.15390	1.67480	1.56040		1.29400	4.28940	0.94346
5.97110	0.90342	1.36860		0.96699	1.91210	0.61320
3.33380	1.35790	0.65991		3.10440	3.35580	1.19150
1.34050	5.15640	0.73376		3.40530	3.18680	1.03920
4.58330	2.50350	0.53137		2.46560	1.32910	0.66239
4.58240	3.90950	1.31030		1.83690	1.95390	0.86711
1.54760	0.49018	1.23250		3.11410	2.79870	1.58460
3.78120	3.02020	1.19850		2.68870	4.90220	1.61410

NEW RELEASE ALERT

Updated ESAMS 5.0

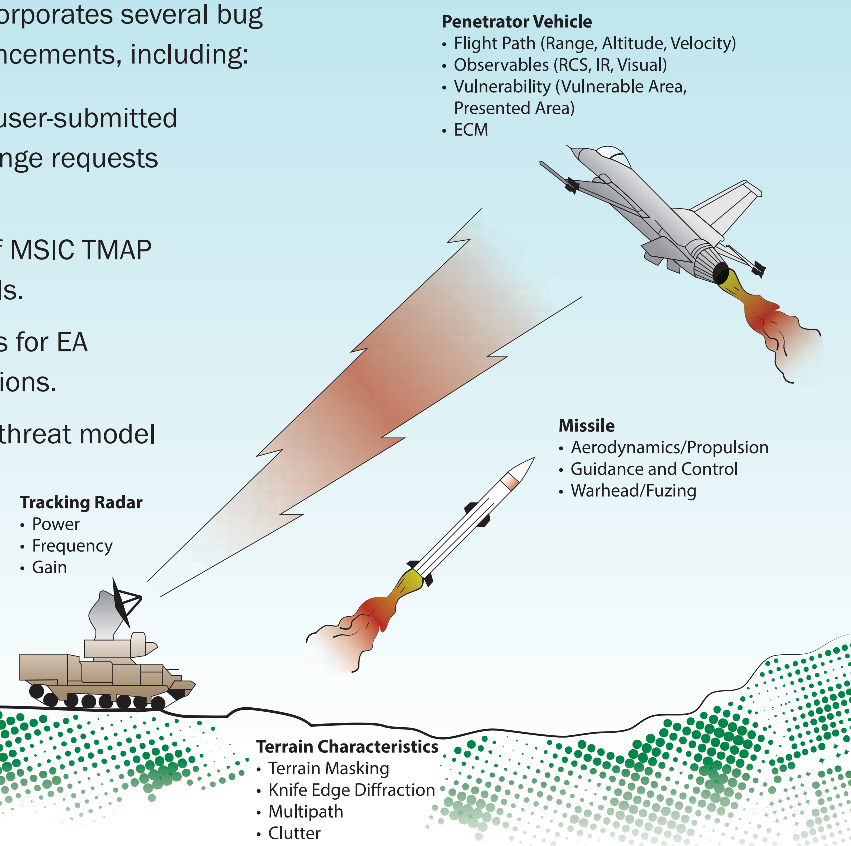
DSIAC, on the behalf of AFL-CMC/EZJ, would like to announce the latest release of the Enhanced Surface-to-Air Missile Simulation (ESAMS), version 5.0, with respective documentation.

The ESAMS software model is a program used to simulate the interaction between an airborne target(s) and a surface-to-air missile (SAM) air defense system. ESAMS is routinely used by the user base to estimate aircraft survivability, estimate effectiveness, set requirements, and develop concept of operations (CONOPS) and tactics. ESAMS simulates the relevant pieces of a SAM engagement, which include radio frequency (RF) radars, detailed area performance, countermeasure algorithms, environmental factors (e.g., terrain, clutter, multipath, noise), tactics (launch computer, target maneuvers), and endgame. ESAMS runs on, and is supported by, Linux and Microsoft Windows.

ESAMS 5.0 incorporates several bug fixes and enhancements, including:

- 20+ ESAMS user-submitted sortware change requests (SCRs).
- Integration of MSIC TMAP threat models.
- Code updates for EA characterizations.
- ESAMS SAM threat model updates. ■

For more information, call 443.360.4600 or e-mail contact@dsiac.org



to test the researcher's hypothesis. This data set is a smaller subset of a much larger data set generated by the researcher's overall work-related study. The table is arranged by take-off (left) and landing (right) factors sub-divided into the respective azimuth levels considered for each factor. Two discrete data groups subdivided into three subgroups are shown. Note that the PCA miss-distance data are depicted as unitless values to protect the sensitivity of the subject matter.

Figures 1 and 2 are half-normal probability plots (p-plot) for each of the six azimuth levels summarized in Table 1.

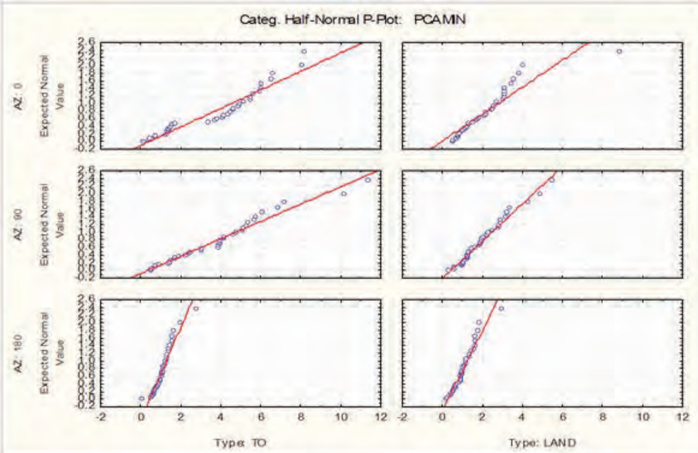
Figure 3 is a histogram plot of the number of PCA magnitude value observations within each specific data level in Table 1. A fitted, normalized curve through the data is represented by the red line.

Figure 4 is a plot of the unweighted mean PCA miss-distance values for the azimuth levels within each flight regime factor. Each mean value point is characterized by its respective 95% confidence limits (vertical bars).

Figure 5 is a plot of the weighted mean PCA miss-distance values for the azimuth levels within each flight regime factor. As with Figure 9, each mean value point is characterized by its respective 95% confidence limits (vertical bars).

Figure 6 is a box-and-whisker plot of the median PCA miss-distance values for the azimuth levels within each flight regime factor. Each median value point is characterized by maximum and minimum PCA miss distance (vertical bars) for each level as well as the distribution of the middle 50% of each level's data points.

Table 2 summarizes the relevant elements of the researcher's ANOVA analysis. Line (1) represents the analysis of the variation of the mean azimuths between the take-off and



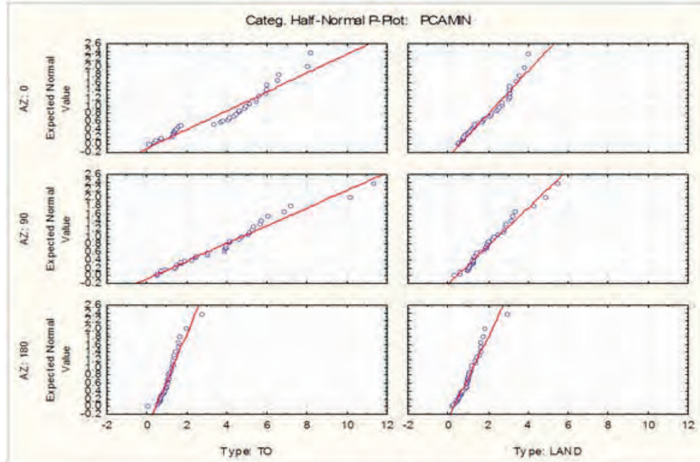
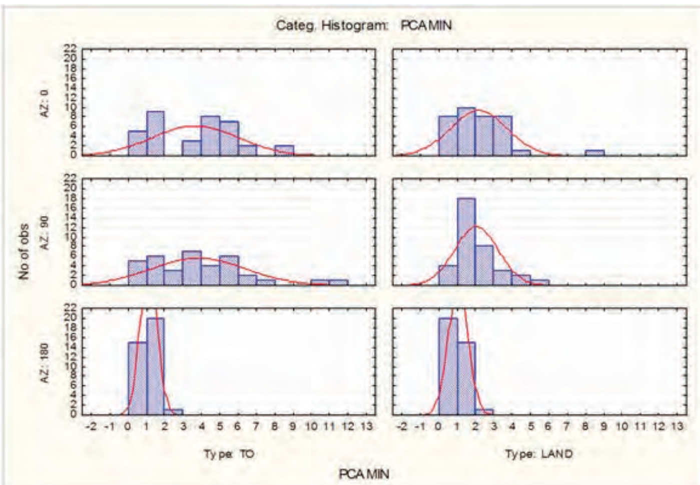


Figure 1 (Left): Half-Normal Probability Plot of Each Data Level, Including Outlier Data.
Figure 2 (Right): Half-Normal Probability Plot of Each Data Level, Excluding Outlier Data.



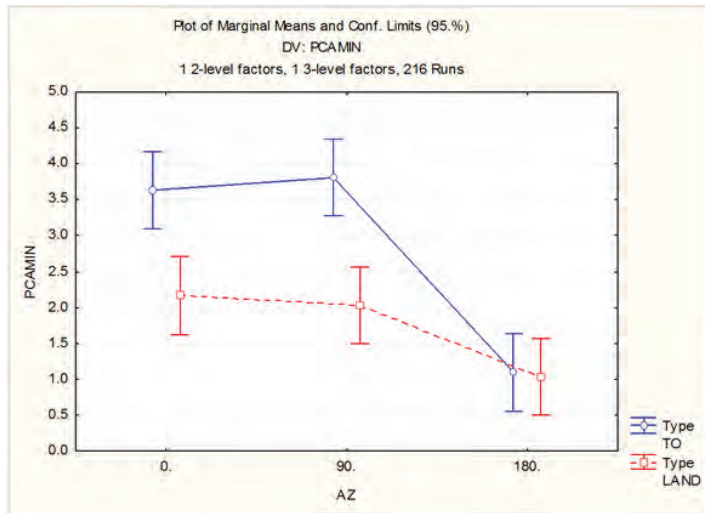
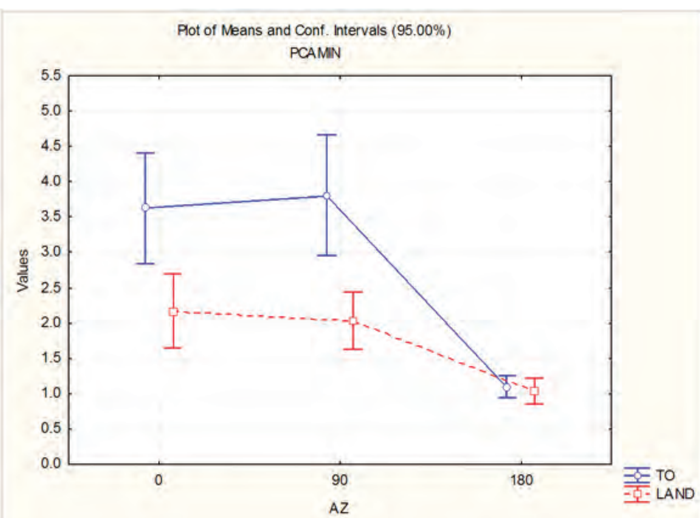


Figure 3 (Left): Distributions of PCA Miss Distance Values for Each Data Group.
Figure 4 (Right): Plot of Unweighted Means for Each Data Group at the 95% Confidence Interval.



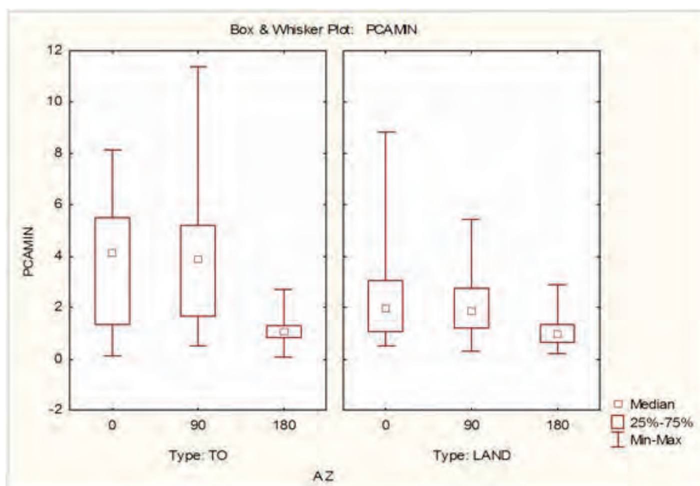


Figure 5 (Left): Plot of Weighted Means for Each Data Group at the 95% Confidence Interval.
Figure 6 (Right): Distributions of Minimum/Maximum Values About the Median for Each Data Group.

Table 2: ANOVA Analysis

Factor	ANOVA; Var.:PCAMIN; R-sqr=.31503; Adj:.29872 1 2-level factors, 1 3-level factors, 216 Runs DV:PCAMIN; MS Residual=2.685887				
	SS	df	MS	F	p
(1)Type L	65.8164	1	65.81640	24.50452	0.000002
(2)AZ L+Q	163.6008	2	81.80042	30.45564	0.000000
1*2	29.9951	2	14.99753	5.58383	0.004338
Error	564.0364	210	2.68589		
Total	823.4487	215			

landing flight mode factors (groups). Line (2) represents the analysis of the variation of the mean azimuths within each azimuth level (nose, beam, tail) for the take-off and landing factors. The line denoted as 1*2 represents a multiple comparison test for interactions between the means and all possible combinations of means.

DISCUSSION

Data Set

Previously expressed is the researcher's expressed theory that certain combinations of independent missile launch parameters and aircraft flight regimes could significantly influence the simulated end-game outcome of the engagement. While the overall project studied many of these interactions and resultant outcomes, the specific relationship of the launch azimuth's influence on the resultant magnitude of PCA miss distance was chosen to test the hypothesis.

PCA miss distance is a particularly powerful dependent variable. A similar dependent variable that could have been tested was simple missile hit or miss. However, due to its binary nature, many more replicates would have been required to achieve the desired confidence interval of 95%. Alternatively, PCA's scalar (or nonbinary) nature allowed the hypothesis to be tested to the 95% confidence interval in significantly fewer replicates. This is a prime example of the effective use and benefit of DOE principals and is consistent with the researcher's goal to improve the efficiency of traditional survivability assessments.

As summarized in Table 1, the launch parameters (independent variables) were aggregated into three populations, where all elevations and ranges were considered equally for launch azimuths that targeted generally about the tail, beam, or nose regions of one side of the subject aircraft. Missile engagement symmetry on the opposite side of the aircraft was assumed. PCA miss distances were considered for each of these populations with the aircraft in two different flight regimes: take-off and landing. A total of six launch parameter groups and their PCA miss distances were analyzed. Direct hits were ignored in this study.

Data Quality

A half-normal probability plot was generated on each data group to verify the quality of the data by evaluating the normality of the distribution of PCA—that is, the extent to which each resultant PCA outcome followed or deviated from the expected normal PCA distribution. The researcher's purpose for these plots was to quickly visualize any peculiar outlying data points so that they could be examined closer for validity. If outliers were uncovered and found to be invalid due to equipment malfunction, operator error, or data collection difficulties, they could be rightfully disqualified as a valid data point. On the other hand, if outliers were not found to be invalid with cause, the influence of the outlying point or points in the analysis could be known and understood.

In Figure 1, the PCAs for each of the data groups follow the expected normal distributions quite satisfactorily. However, the plot representing the nose azimuth/landing configuration grouping revealed a single outlying point that deviated significantly from the expected norm. Upon closer examination, the point can be easily spotted in Table 1 (highlighted) as noticeably larger than the rest of the cohort. Based on a forensic examination of how the point was generated and collected, the researcher determined that the point was valid and thus could not be eliminated with cause.

In the interest of completeness, the researcher eliminated the point and regenerated the half-normal probability plots to see if agreement was improved. In Figure 2, it can be seen graphically that the outlying point's skewing influence was noticeably reduced. The expected normal line became more aligned with the plotted data distribution of PCAs.

In the researcher's judgment, however, keeping or eliminating this single point was of little consequence to the overall analysis. While the point visibly influenced the quality of 1/6th of the data set being analyzed, it was viewed that it would not influence the variation of the entire data set to any significant degree. The point was not eliminated because the validity of how it was measured and collected was intact.

Data Distribution

In Figure 3, the simple distribution of PCA observations for each data group reveals visually the heavy influence of launch azimuth on the magnitude and variation of PCAs in both the take-off and landing flight regimes.

For tail engagements, the histogram in Figure 3 indicates virtually no difference between the take-off and landing flight regimes, with only slight variation in PCA magnitude. As the engagements come around to the beam and tail aspects, the variation in PCA magnitude becomes more pronounced. The distributions of the take-off PCA magnitudes were significantly flatter than the distribution of landing PCA magnitudes.

The entire data set was used to generate 95% confidence intervals about unweighted means in Figure 4. While the confidence limits about the mean for each data group are consistently spaced between them, the distribution of the PCA observations in the histograms in Figure 3 is not accurately reflected.

...an opportunity to apply DOE methods in an attempt to document potential improvements to an older, less efficient process.

Conversely, data within each group were used to generate 95% confidence intervals about weighted means in Figure 5. In doing so, the confidence limits become sized differently between the data groups. When qualitatively compared to the histograms in Figure 3, the confidence intervals in Figure 5 become more representative.

Overall, Figures 4 and 5 show both the linear and quadratic interactions of the azimuth groups between the take-off and landing flight regimes. Mean PCA values about the tail aspects do not seem to be influenced by launch azimuth. However, mean PCA values about the beam and nose aspects indicate marked influence of launch azimuth. Figures 4 and 5 were the researcher's first look at whether azimuth variation caused a difference in PCA magnitude and where the greatest variance within the data groups may lie.

Figure 6 depicts the range of minimum and maximum PCA values, the median PCA value, and the range of PCA values about the median for the middle 50% of PCA observations. Figure 6 further reinforces the influence of launch azimuth on the variation and magnitude of PCA.

Analysis

Previously described is the variation and distribution of the means for two factors with three levels each. To test for significant differences between the means, the variances between them were inferentially analyzed using the ANOVA method.

Had the researcher limited the analysis to simply the variance between the azimuth means of the take-off and landing factors, a routine t-test would have sufficed. However, additional independent information about where and why differences (or features) existed could not be considered using this method alone. Instead, an ANOVA analysis permitted the partitioning of between-level and within-level sum-of-squares that characterized layers of independent information not afforded by the t-test.

In what would have been a comparatively more complex process, the researcher had the simplifying advantage of using Statistica™ to perform the ANOVA analysis on the chosen data set(s). With minimal researcher input, Statistica™ rapidly generated and tabulated (see Table 2) the ANOVA into its relevant statistical constituents: sum of the squares, degrees of freedom, mean squares, Fisher (F) statistic, and p-value.

Conventional statistics suggest that if F is large (F>>1.0), then differences exist. Likewise, if the supporting p-value is small (p<0.01), this suggests the differences are more probable than would be expected by mere chance alone. When comparing the azimuth means between the take-off and landing factors (Table 2, (1)), an F statistic of 24.50452 with a p-value of 0.000002 was calculated. When comparing the azimuth means within the nose, beam, and tail levels (Table 2, (2)), an F statistic of 30.45564 with a p-value of 0.0 was calculated. The post-hoc multiple comparison interaction (Table 2, (1*2)) between (1) and (2) resulted in an F statistic of 5.58383 with a p-value of 0.004338. The calculated F statistic was lower than the other two cases and supported by a higher p-value implying a clear interaction between less apparent data features.

Conventionally, the p-value would be limited (i.e., 0.01) so a critical F statistic could be determined (via lookup table) using the degree of freedom values. However, because the F statistics for all three cases were so overwhelmingly large supported by correspondingly low p-values, the researcher felt testing the calculated values of F against critical F statistic values found in a look-up table was not necessary. Adequate analysis of the null hypothesis could be performed as it stood.

CONCLUSIONS

The null hypothesis states that certain missile launch azimuths about the target aircraft do not contribute to significantly different magnitudes in the resultant simulated PCA miss distances to the aircraft. This hypothesis suggests that the variance of the PCA miss distance means between the factors and within the levels should be identical. However, based on the analysis performed, this was not the case. Supported by both descriptive and inferential statistical tests, the researcher observed unusually high variances in the mean PCA miss distances as a function of launch azimuth that supports the rejection of the null hypothesis. The conclusion is that launch azimuth heavily influences the simulated end-game outcome of the missile-to-aircraft engagement in terms of PCA miss-distance magnitude.

> The initial results of this study have far-reaching implications for the advancement of aircraft survivability science.

On the basis of descriptive statistics alone, the researcher might have correctly concluded that the distributions of the data as well as the obvious visual variances in the magnitude of the PCA miss-distance observations suggested a heavy dependence on launch azimuth. However, in the interest of completeness, quantifying the analysis further through an ANOVA could only lend credibility to what seemed obvious initially.

As suspected, the results of the ANOVA proved to be conclusive. The high F statistic values for cases (1) and (2), supported by virtually zero probability (p-value) that the variances in the PCA miss-distance means were due to chance, supported the researcher's initial suspicion based on descriptive observations alone. The smaller F statistic and probability calculated in the multiple comparison tests did suggest one or more of the azimuth levels might be a greater contributor to the PCA variances observed. However, the F statistic was still much greater than a look-up critical F statistic based on the degrees of freedom, and the probability remained low. Ultimately, it was felt that the hypothesis had been adequately tested at this level of analysis even though there are evident grounds that deeper analysis is warranted. Recommendations to those ends are discussed as follows.

RECOMMENDATIONS

Specific to testing this hypothesis, the unusually high F statistics and low p-values imply highly probable, significant differences that support the researcher's hypothesis. However, what are not revealed are the details of additional potential data features and interactions that the researcher suspects exist. The results only suggest a broad feature space within which more research could be performed. The introduction of more refined azimuth levels could serve to differentiate in greater detail specific contributing features/

interactions that were confounded by the generalized scope of the azimuth levels chosen for this study to protect the classification of the subject matter. Additionally, consideration of other launch parameters (e.g., range and elevation) may add dimension to the feature space of the data set, further refining the causal aspects of missile hit-point and miss-distance evaluations in general.

The initial results of this study have far-reaching implications for the advancement of aircraft survivability science. As asserted previously, the demand on the aircraft survivability research community to discover, understand, and offer mitigating survivability solutions is a challenging undertaking, and this challenge must be met more wisely and more innovatively through advanced technologies and methods.

Until recently, most survivability assessments or evaluations have been stuck in the rut that is open-air live fire verification testing. As systems have become increasingly more complex (and in turn more expensive), subjecting them to actual combat damage is not practical. It seems the advancement of M&S technologies and methods is the next logical progression in survivability science and should serve nicely as an economic solution with increasing influence in the survivability research community.

While this body of research was funded specifically to address the survivability posture of a particular airframe, it has served nicely as a platform for advancing the known techniques for doing so. The researcher had two stated objectives: establish a susceptibility baseline for an unprotected commercial-derivative large aircraft against a typical ground-launched missile threat and narrow the scope of follow-on vulnerability assessments to areas on the aircraft that have the highest vulnerability potential. Both were achieved using highly specialized HITL simulation and aircraft modeling techniques for a fraction of the cost of performing open-air live fire verification testing.

DOE studies produced more robust, informative results in fewer runs by almost half.

The M&S techniques are sound and are becoming more and more capable. However, verification and validation of these techniques remain significant issues. The credibility of the results is continually scrutinized and criticized. In as much as a great deal of effort has been poured into expanding the M&S capabilities in ACS, the researcher recommends all prospective practitioners to exert an equal amount of effort in verifying and validating their techniques to counter the certain criticism.

Although DOE has been a dominant player in manufacturing for some time, in Defense test and evaluation (T&E) it is a relative newcomer. DOE is a vastly different approach to traditional Defense T&E and thus has been a tough sell for most. Nonetheless, this researcher used DOE principles for the first time throughout this project and is convinced it is a more productive and less costly way forward for this type of work.

When directly compared to similar past studies conducted using traditional methods, the DOE studies produced more robust, informative results in fewer runs by almost half. Correspondingly, the schedule and thus cost were significantly reduced. The obvious advantages of practicing DOE principles notwithstanding, the researcher recommends that all survivability researchers incorporate the use of DOE in their future assessments and evaluations. ■

BIOGRAPHY

ROBERT (WINK) YELVERTON is the General Manager of the SURVICE Engineering Company's Gulf Coast Operation. His diverse technical and management experience spans a 28-year career within the Defense scientific industry, affording him several key leadership and support roles on numerous high-visibility developmental programs and acquisitions. His professional/research interests include air/ground vehicle survivability, human injury studies, vulnerability M&S, lethal assessments, sustainable energy alternatives, and renewable resources. Mr. Yelverton earned B.S. in Geology/Geophysics from the University of New Orleans in 1985 and an M.S. in Aeronautical Science from Embry-Riddle Aeronautical University in 2008. He is the treasurer of the Doolittle Institute's Board of Directors.

THE PBL GUIDEBOOK:

PRACTICAL HELP FOR THE EFFICIENCY-EFFECTIVENESS CHALLENGE

By Eric Fiore

Few people would debate that the United States possesses one of the most effective militaries in the world. One could argue this effectiveness stems largely from our determination, resources, and ability to fund our ventures until they are either successfully deployed or terminated. However, all the branches of our military are being asked today to reduce costs by operating more efficiently without reducing their effectiveness. Fueling this imperative is a perception that there are widespread inefficiencies in military system sustainment programs, and thus these programs represent "low-hanging fruit" to be harvested by budget hawks. Consequently, fevered arguments about the United States' ability to increase efficiency without decreasing effectiveness dominate the media every day. Many of these arguments focus largely on semantics, and the reality is that U.S. forces ultimately (and historically) have become as efficient and effective as needed to perform the missions prioritized by national leaders.

This point was recently reiterated in an online debate on the LinkedIn - International Systems Engineering Network. Mr. Tom Mathis, of Strategic Operational Solutions, posted:

"I think it is always important to avoid semantic debates by only using a meaningful lexicon that provides clarity. I have always used "efficiency" within the context of measurable costs, e.g., time, money, human capital, etc. An "efficient" systems/activity/method/process etc. was one that was well worth the "costs", i.e., sustainable. Whereas "effectiveness" is all about how well the systems/activity/method/process achieved the desired effect. So a systems/activity/method/process can be very effective, but inefficient. "Efficiency" is always a relative term to what costs are sustainable by a system. The acceptable costs are a function of the value proposition of the resulting effectiveness of the systems/activity/method/process. Take for example the extreme cost during the Cold War to maintain a fleet of strategic bombers, nuclear submarines, and intercontinental ballistic missiles always ready to go—it was the most efficient way to maintain a very effective deterrent for nuclear aggression."

Such sentiments highlight the issue many branches of the Department of Defense (DoD) community are having to confront as certain pundits continue to argue that the highly effective U.S. military may be over-achieving with regard to the needs of contemporary policy. To meet these needs while still sustaining the highest possible level of capability, the military will have to consider employing methods that can help adapt its sustainment approach to align with available resources.

One such approach used by both the commercial industry and the military that is regaining popularity is Performance Based Logistics (PBL). The concept of a PBL system has been around since the 1990s, but initially it suffered from some skepticism and mixed reviews by Government officials who felt the system lacked sufficient transparency to perform an accurate value assessment. However, more recent successes with PBL have identified it as a tool that can help sustain warfighting capability at a lower cost.

In an effort to promote greater acceptance and use of PBL, implementation guidance was specifically specified as part of

continues on page 36

the Better Buying Power (BBP) initiative, which included the development of a PBL Guidebook. Accordingly, the Office of the Assistant Secretary of Defense for Logistics and Materiel Readiness (ASD[L&MR]), in collaboration with the Services and Defense Acquisition University (DAU), developed the PBL Guidebook to assist the Defense acquisition workforce in developing effective PBL product support arrangements.

The DoD PBL Guidebook was issued by the Acting ASD(L&MR) on 27 May 2014. This guidebook is designed to serve as both a reference manual for experienced PBL practitioners, as well as a practical "how-to" guide for new-to-PBL logisticians.

The guidebook complements DoD policies and guidance while providing PBL best practices and practical examples. Additionally, the guidebook provides a consolidated resource that leverages DoD instructions, other guidebooks, and the Product Support Business Model as an organizing construct for PBL best practices, processes, and supporting documentation needed to craft effective PBL or performance based product support and arrangements. The guidebook also supports DoD policy outlined in the ASD(L&MR) "Performance Based Logistics Comprehensive Guidance" memorandum.

The PBL guidebook is being made available on the DoD Performance Based Logistics Community of Practice (PBL CoP) to ensure it is readily accessible to a broad, interdisciplinary team of program managers, product support managers, life cycle logisticians, contracting officers, financial managers, systems engineers, and other stakeholders with life cycle product support and sustainment responsibilities. It is intended to be used in conjunction with a range of related resources included elsewhere in the PBL CoP; and key product support policy, guidance, tools, and training are available on the Product Support Key References site of the DAU Logistics CoP.

The PBL Guidebook is available at https://acc.dau.mil/pbl-guidebook ▸. ■

NEW RELEASE ALERT

Updated Vulnerability Toolkit

The Vulnerability Toolkit comprises five computer applications intended to be run independently or in concert. The latest kit includes the following computer applications:

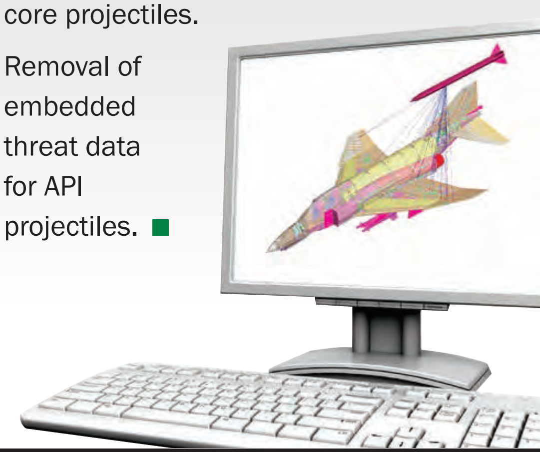
COVART 6.5	FATEPEN 3.3.8
FASTGEN 6.1.1	ProjPen 2.6
BRL-CAD 7.12.4	

This latest release of the Vulnerability Toolkit includes improvements to the Computation of Vulnerable Area Tool (COVART 6.5) as well as an updated version of the Projectile Penetration (ProjPen 2.6) library.

The COVART computer program is a method for determining the vulnerable areas of targets damaged by impacting single kinetic-energy (KE) penetrators, shaped charge jet penetrators (SCJ), and high-explosive (HE) threats (including man-portable air defense systems [MANPADS] and proximity-fuzed warheads). COVART supports both FASTGEN and BRL-CAD targets in their native format and runs on Windows and Linux operating systems. ProjPen is used to perform penetration calculations for projectiles; FATEPEN is used for fragments.

COVART 6.5 incorporates several bug fixes and enhancements, including:

- Input file line number reporting when input errors are encountered.
- User control over supplemental diagnostic file names and removal of FORTRAN logical unit numbers (LUNs) from the user control in the MASTER file.
- Re-instatement of the AMU1 and AMU2 fragment orientation angles for FATEPEN fragments.
- Updated application programming interface (API) threat file format to accommodate changes to the ProjPen library.
- ProjPen 2.6 includes several bug fixes and enhancements, including:
- Support for mild steel core ball round projectiles.
- Improvements to the ballistic limit calculations.
- Fixes for depleted uranium (DU) core projectiles.
- Removal of embedded threat data for API projectiles. ■



For more information, call 443.360.4600 or e-mail contact@dsiac.org ▸

USE DSIAC TO DO MORE & SPEND LESS

The Department of Defense (DoD) community continues to be driven to do more with less by embracing opportunities to improve efficiency and life-cycle costs. The Defense Systems Information Analysis Center (DSIAC) serves as a gateway to seize upon untapped synergetic opportunities that lie within the Defense Systems community. DSIAC efficiently accesses the enormous repository of important DoD scientific and technical information (STI) that has been generated over the past half century and makes it available on demand to the DoD and supporting Defense Systems industrial and research communities. DSIAC provides access to this wealth of knowledge and information network via a consortium of scientists, engineers, and information specialists that are available to answer technical questions and perform specialized analyses.

FREE DSIAC TECHNICAL INQUIRY SERVICES

DSIAC's core function is to answer technical questions from the community using our own knowledge management experts, vast DoD information resources, and extensive network of subject-matter experts (SMEs). The DSIAC SME network includes experienced engineers and scientists, military and civilian personnel, leading academic researchers, and industry experts who are readily available to help prepare timely and authoritative answers to complex Technical Inquiries (TIs). DSIAC's free TI research service is limited to 4 research hours per inquiry, and requesters must meet the appropriate eligibility and need-to-know requirements to access export-controlled technical information, DoD technical information, and classified information.

TIs can be submitted to DSIAC via our website, or by e-mail, phone, or fax. Once submitted, the inquiry is forwarded to a research analyst who responds to the inquiry or identifies the SME(s) best suited to answer the question. DSIAC makes every effort to support fast-response, mission-critical TIs. Completed responses are compiled and delivered to the requester within 10 business days.

When appropriate, DSIAC may also provide additional information to clarify or augment TI responses, including supporting data, analysis results, or other technical information extracted from formal reports, papers, and other documents. If the level of inquiry research is expected to exceed DSIAC's free 4-hour limit, the requester is contacted to determine if a more extensive, separately funded support is required. These distinct, customer-funded DSIAC activities are known as Core Analysis Tasks (CATs).

DSIAC CORE ANALYSIS TASK SERVICES

Challenging technical problems that are beyond the scope of the free 4-hour TI can be investigated with a CAT request. CATs are separately funded research activities that extend beyond the DSIAC Basic Center of Operation (BCO) services. Via a CAT request, DSIAC can be used as a contracting vehicle, enabling the DoD community to obtain specialized support for specific projects. The projects must be within the technical scope of DSIAC and must result in the generation of formal STI, such as a technical report, data, analysis, or other formal deliverable product. The DSIAC scope includes Advanced Materials; Autonomous Systems; Directed Energy; Energetics; Military Sensing; Non-Lethal Weapons; Reliability, Maintainability, Quality, Supportability, & Interoperability (RMQSI); Survivability and Vulnerability; and Weapon Systems.

ADVANTAGES OF DSIAC CAT SERVICES

- **Fast Track Accessibility –** DSIAC is a pre-competed, single-award, indefinite delivery/indefinite quantity contract, so work can begin in as little as 4 weeks.
- **Expansive Technical Domain –** DSIAC's broad scope provides a wide and deep pool of resources for projects, which is especially valuable for efforts that cross multiple domains.
- **Large SME Network –** DSIAC can leverage support from its expansive SME network to perform CATs.

- **Multiple STI Databases –** DSIAC has access to an enormous repository of data and information to support the execution of CATs, including the STI collections from the six legacy Information Analysis Centers (IACs), the Defense Technical Information Center (DTIC) Research and Engineering (R&E) Gateway, and specialized DoD and Government databases and repositories not routinely accessible to the community.
- **Up-to-the-Minute Information –** DSIAC can draw from the most recent studies performed by for agencies across the DoD, as the results from all DSIAC CATs and Defense Systems Technical Area Tasks (TATs) are collected, stored, and used to support ongoing DSIAC efforts.

STARTING IS FREE & EASY

As shown in Figure 1, the first step to using DSIAC is to contact us with a TI, and the first 4 hours of TI research are conducted free of charge. If the scope of the effort exceeds the free threshold, DSIAC will contact the requester to determine if the scope of the effort qualifies as a CAT. DSIAC will then assist with the development of a statement of work (SOW). The SOW must be approved by the DSIAC Contracting Officer's Representative (COR), the IAC Program Management Office (PMO), and the DSIAC Contracting Officer to ensure it meets the requirements of the DSIAC contract. Based on the SOW requirements, DSIAC will then prepare a technical and cost proposal, which must also be approved by the customer and the Contracting Officer.

Each CAT is limited to a 12-month period of performance and a cost ceiling of $1 million. CATs can be requested by anyone in the DoD community as well as non-DoD Government agencies and departments. For more information on the IAC CAT program, including the standard operating procedure for ordering CATs, contact us by phone at 443.360.4600 or by e-mail at **contact@dsiac.org**. You can also visit the DSIAC website at **www.dsiac.org** or the IAC website at **http://iac.dtic.mil** for more information. The IAC website also archives mission success stories from the many projects performed by the various IACs and provides excellent examples of how the IACs solve complex problems by providing expert service to the DoD community. ■

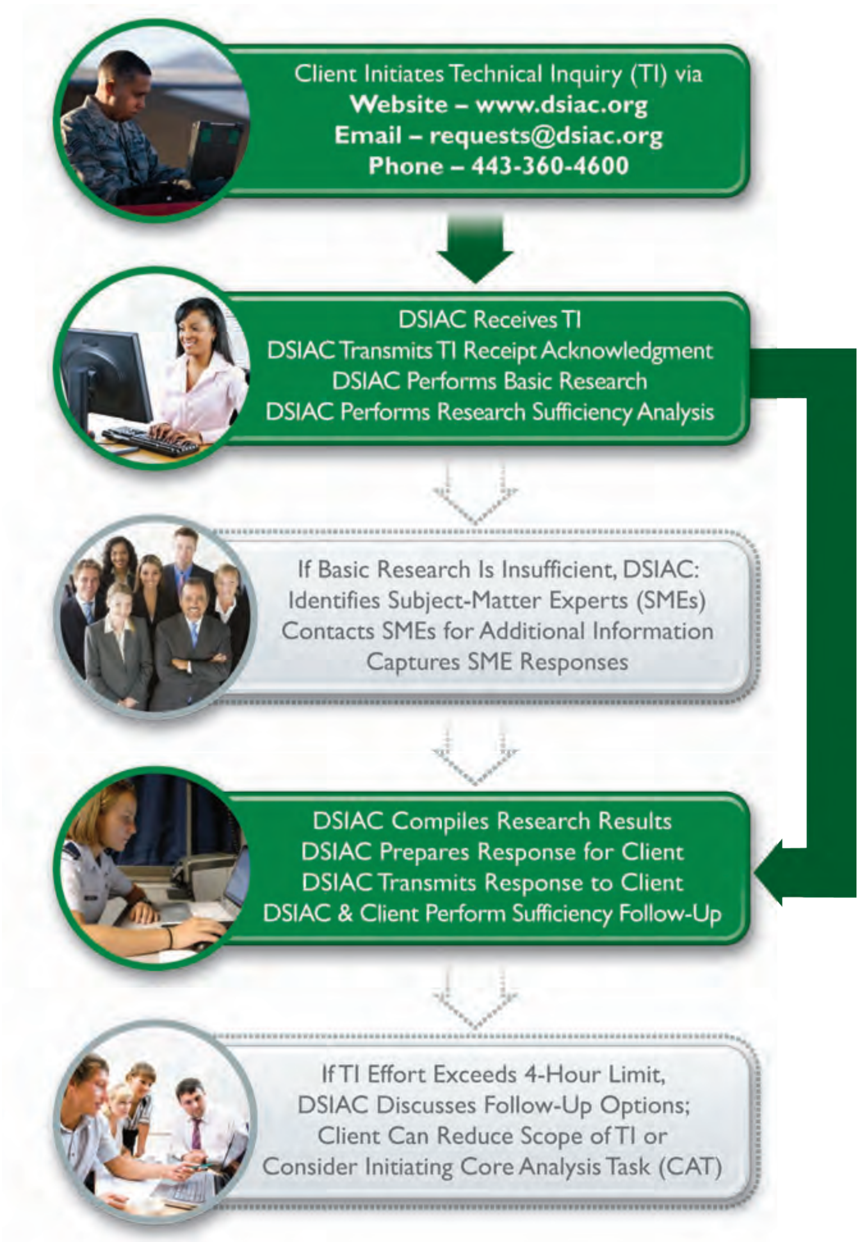


Figure 1: DSIAC Technical Inquiry Process.

CONFERENCES AND SYMPOSIA

OCTOBER 2014

2014 International Test and Evaluation Symposium Association (ITEA) Annual Symposium
6–9 October 2014
Arlington, VA
http://itea.org/conferences74/35-share/conferences/312-31st-annual-international-test-and-evaluation-symposium.html

51st Annual AOC International Symposium and Convention
12–16 October 2014
AOC - Indiana Convention Center and Marriott Downtown, Indianapolis, IN
http://www.crows.org/conventions/conventions.html

IEEE International Integrated Reliability Workshop
12–16 October 2014
Fallen Leaf Lake, CA
http://www.iirw.org/home.html

17th Annual Systems Engineering Conference
27–30 October 2014
Springfield, VA
http://www.ndia.org/meetings/5870/Pages/default.aspx

2014 IEST Fall Conference
27–30 October 2014
Cary, NC
http://www.iest.org/Meetings/Fall-Conference

Human Factors and Ergonomics Society (HFES) 2014 Annual Meeting
27–31 October 2014
Chicago, IL
http://www.hfes.org/web/HFES-Meetings/2014annualmeeting.html

NOVEMBER 2014

11th Avionics, Fiber-Optics & Photonics Conference
11–13 November 2014
Hyatt Regency Atlanta
Atlanta, GA
http://www.osa.org/en-us/meetings/global_calendar/events/11th_avionics,_fiber-optics_photonics_conference/

Aircraft Survivability Technical Forum
12–14 November 2014
Johns Hopkins University APL
Laurel, MD
http://www.ndia.org/meetings/5940/Pages/default.aspx

19th Annual Expeditionary Warfare Conference
17–19 November 2014
Norfolk Marriott Waterside
Norfolk, VA
http://www.ndia.org/meetings/5700/Pages/default.aspx

12th Annual NanoTechnology for Defense Conference
17–20 November 2014
Westfields Marriott Washington Dulles
Chantilly, VA
http://usasymposium.com/nano/

IEEE Green Energy and Systems Conference
24 November 2014
Pyramid, California State University, Long Beach
Long Beach, CA
http://www.ieee.org/conferences_events/conferences/conferencedetails/index.html?Conf_ID=33476

MRS Fall Meeting & Exhibit
30 November–5 December 2014
Hynes Convention Center & Sheraton Boston Hotel
Boston, MA
http://www.mrs.org/fall2014/

DECEMBER 2014

I/ITSEC (Interservice/Industry Training, Simulation & Education Conference)
1–4 December 2014
Orange County Convention Center
Orlando, FL
http://www.iitsec.org/Pages/default.aspx

Defense Logistics Conference
2–4 December 2014
Hilton Alexandria Mark Center
Alexandria, VA
http://defenselogistics.wbresearch.com/agenda

Joint Army-Navy-NASA-Air Force (JANNAF) 46th Combustion/34th Airbreathing Propulsion/34th Exhaust Plume and Signatures/28th Propulsion Systems Hazards Joint Subcommittee Meeting
8–11 December 2014
Hyatt Regency Albuquerque
Albuquerque, NM
https://www.jannaf.org/mtgs/Dec2014/pages/index.html

29th International Maintenance Conference
8–12 December 2014
Hilton Daytona Beach Ocean Walk
Daytona, FL
http://imc-2014.com/

Combat Systems Symposium
9–10 December 2014
JHU APL Kossiakoff Conference and Education Center
Laurel, MD
https://www.navalengineers.org/events/individualeventwebsites/Pages/CombatSystems2014.aspx

Note: For the latest listing of events related to Defense Systems, please visit www.dsiac.org/events

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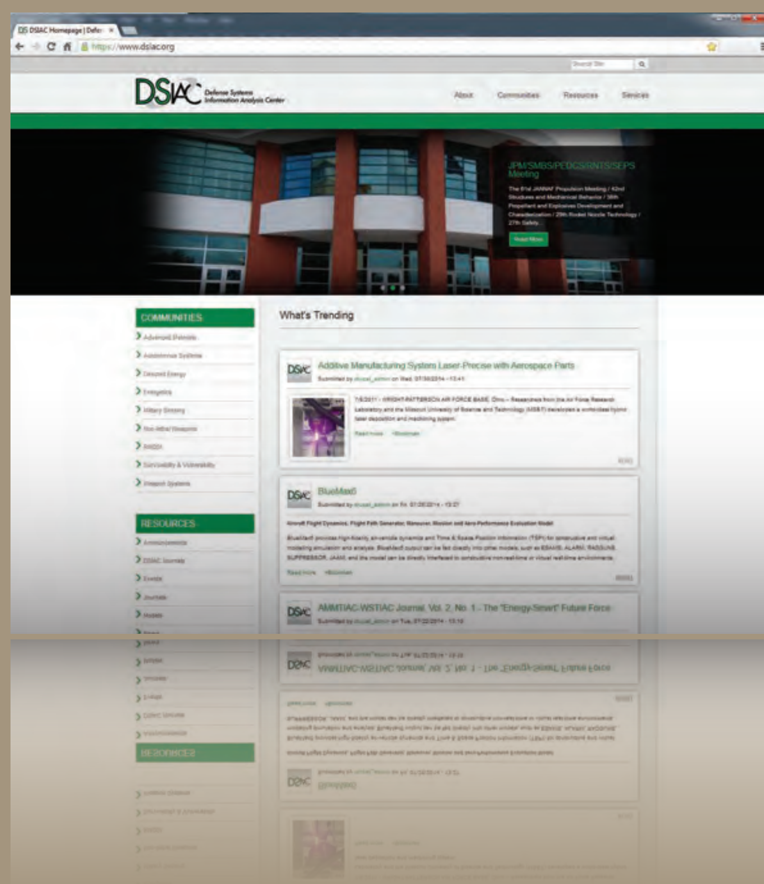
- Participating in key DoD conferences and forums to engage and network with the S&T community.
- Performing customer-funded Core Analysis Tasks (CATs) under pre-competed IDIQ Delivery Orders.



DSIAC SCOPE AREAS INCLUDE:

- Advanced Materials
- Autonomous Systems
- Directed Energy
- Energetics
- Military Sensing
- Non-lethal Weapons
- Reliability, Maintainability, Quality, Supportability, and Interoperability (RMQSI)
- Survivability and Vulnerability
- Weapon Systems