

# DSIA JOURNAL

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# DSIAC

## JOURNAL

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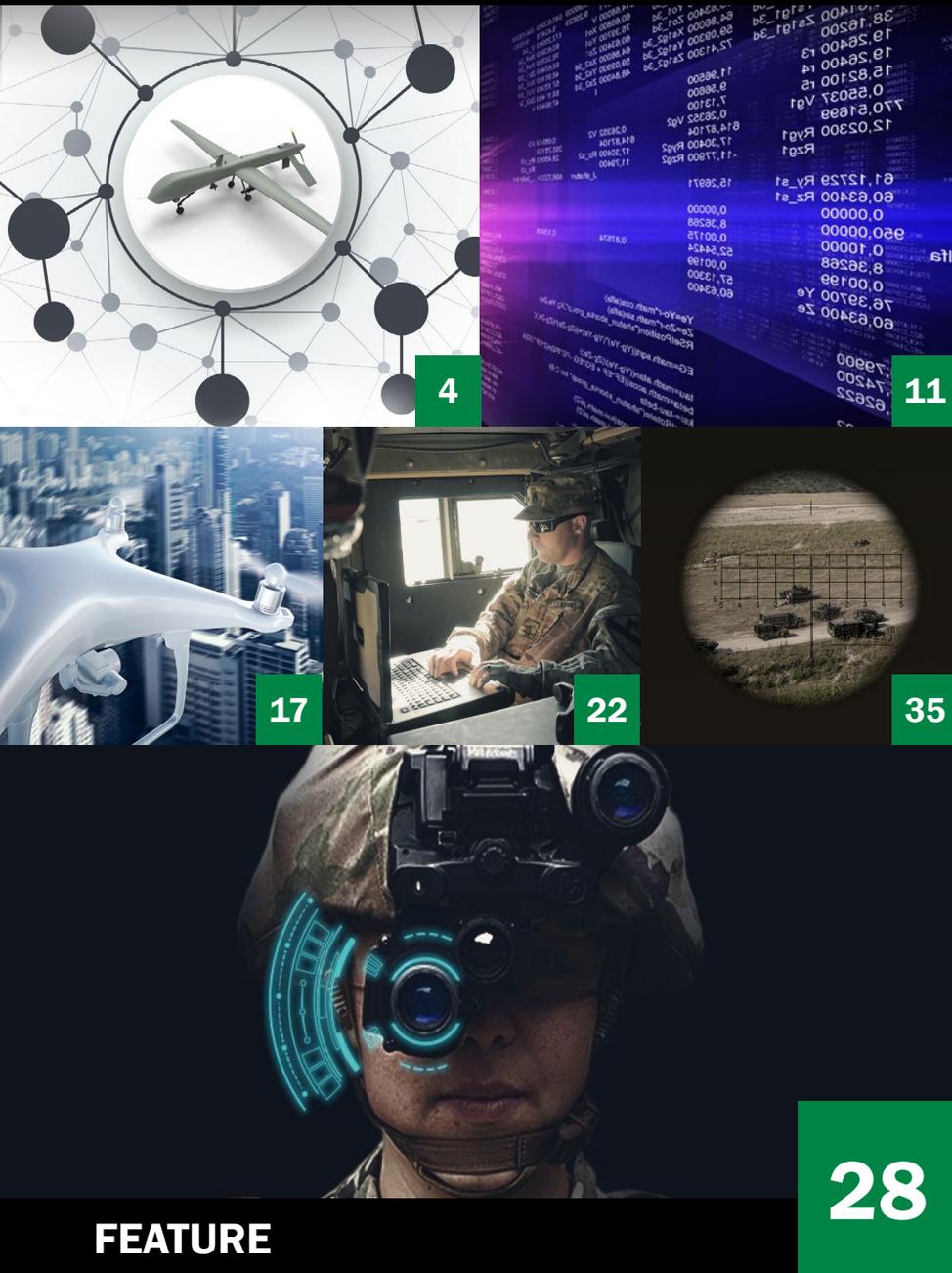
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#### Focus Area Key:

<b>AM</b> Advanced Materials	<b>EN</b> Energetics	<b>RQ</b> RMQSI
<b>AS</b> Autonomous Systems	<b>MS</b> Military Systems	<b>SV</b> Survivability & Vulnerability
<b>DE</b> Directed Energy	<b>NW</b> Non-lethal Weapons	<b>WS</b> Weapon Systems

## FEATURE

### Augmented Target Recognition Display Recommendations

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**MS** Military Sensing

In light of the U.S. Army's intent to leverage advances in artificial intelligence for augmenting dismounted Soldier lethality through developing in-scope and heads-up display-based augmented target recognition (ATR) systems, this article identifies several critical gaps that must be addressed in order to effectively team the Soldier with ATR for the desired augmented lethality.

# SYSTEM CAPABILITIES ANALYTIC PROCESS

and Advanced Teaming Analyses

By Andrew Drysdale

operator  
incapacitated

ballistics

electronic  
warfare

team  
returns to  
base

(Source: 123rf.com)



## BACKGROUND

**A**mong the principal responsibilities of the U.S. Army's Combat Capabilities Development Command/Data and Analysis Center (CCDC/DAC) is supporting many Army test and evaluation (T&E) programs. These programs come in a wide variety of forms and may attempt to characterize the effectiveness, safety, reliability, lethality, vulnerability, survivability, and/or susceptibility of relevant combat systems. DAC's T&E responsibilities include planning, executing, and assessing the results of associated testing and increasingly include the performance of modeling and simulation (M&S) work for T&E leverage.

One common type of DAC-performed M&S exercise is the survivability/vulnerability/lethality (SVL) analysis. A typical vulnerability-focused SVL analysis contemplates a single encounter of a target system and a specific threat under controlled conditions and predicts the outcome from an SVL perspective. Modeled threat disciplines may include ballistics, electromagnetic warfare, nonconventional threats, cyberattacks, and others.

SVL analyses tend to be relatively granular (i.e., initial calculations [analytic, numerical, or empirical] focus on determining the probability of dysfunction occurring at the component level). This probability is often smoothed over a domain such as threat incidence angle. Quantification of system-level "kill," or loss, occurs via consulting with a damage assessment list (DAL). The DAL provides an indication of how component dysfunction correlates to the kill of a system's broadly-defined mobility, firepower, or overall availability. Kill results are then combined or averaged, as appropriate, and reported out as the product of the analysis.

A typical vulnerability-focused SVL analysis contemplates a single encounter of a target system and a specific threat under controlled conditions and predicts the outcome from an SVL perspective.

Several drawbacks to the single-system, DAL-based approach have motivated our current work on developing the system capabilities analytic process (SCAP) in the context of DAC's Advanced Teaming Analysis Concept (ATAC).

DAL output often fails to capture the "so what?" of the results. More so than a holistic loss-of-function description, whether a damaged system retains one or more particular capabilities is often the information of greatest interest to evaluators, program managers, downstream analysts, and other customers. Additionally, using a single quantity for a broad category of capabilities (e.g., firepower) often elides the differences between distinct capabilities within that category. (A 0.6 firepower kill could mean many different things in the context of a vehicle with multiple weapons.) These are serious handicaps for determining how a system will operate.

Another issue is that traditional SVL analyses tend to consider the target isolated from operational context. This approach is straightforward but leaves factors such as emergent capabilities and redundancies of the teamed assets, the effects of other encounters within

the mission scenario, and miscellaneous effects (reliability issues, operator error, logistical problems, or even environmental factors) ill considered.

These drawbacks limit the ability of DAC analysis products to transition from answering narrow questions about SVL performance in controlled conditions—the direct focus of much of T&E support—to becoming more broadly applicable in modeling complex engagement scenarios. As the importance of modeling multidomain and teamed systems acting in concert gains increasing acceptance in the Army, approaches that tend to isolate the system in question become less relevant. SCAP development is therefore intended to affect a better correspondence between DAC analyses and the M&S requirements of our partners and customers.

## THE SCAP ANALYSIS AND ATAC IMPLEMENTATION

ATAC is DAC's effort to bring a capabilities-based analysis process to the complex problem of assessing teamed assets. DAC is employing SCAP [1] for team-centered analyses because it is seen as inherently suitable; many collective characteristics of a teamed force are difficult to define solely in terms of individual actors. Work on the ATAC program was performed in fiscal year (FY) 2019 by a multidisciplinary team of DAC engineers: Stephen Abbott, Kevin Agan, Andrew Drysdale, William Landis, SFC Tonio Pearce, and Gina Schafer [2].

When applied to ATAC implementation, the SCAP methodology requires three kinds of input data for model processing:

1. The functional tree, a bidirectional map between individual components and the capabilities they enable.

## ATAC is DAC's effort to bring a capabilities-based analysis process to the complex problem of assessing teamed assets.

2. The event script, which defines the mission scenario and dictates which functionality changes will occur, when, and under what conditions.
3. The status updater, which handles contingency conditions in the event script and the calculation of additional state values (e.g., battery power consumption) at each time step.

The SCAP functional tree is a set of entities (grouped into components/subsystems, functions, and capabilities) that serves to describe how individual components are combined to affect a system's capabilities. By way of example, a portion of a tree is shown in Figure 1. Critical components, and the subsystems they comprise, are the lowest-level entities. Functions are intermediate entities defined by a unique combination of required components or other functions. Conceptually, a function is a "unit of accomplishment" that is observable, measurable, and not normally considered an end unto itself, such as lubricant regulation or power supply.

High-level entities are called capabilities; these are, in turn, defined by a combination of required functions. A capability represents a complete action, such as identifying a target or communicating with base. The most

overarching capabilities are sometimes defined by a set of other capabilities, often involving more than one system, and representing complicated actions such as "engage armored enemy."

Because most groups of components function in series (e.g., a drivetrain requires each of its components working in turn), most functions and capabilities in a SCAP model require the availability of each of their constituent entities. Thus, the great majority of functional tree connections use exclusively "AND" relationships, which are shown in Figure 1 as arrows.

For ATAC, DAC implemented functional trees as signal-processing models in MATLAB's Simulink module. To aid with editing, the unified tree for the team

was split into two steps—one tree maps component/subsystem availability to function availability, and a second tree maps that output to capability availability. The output of the second tree is the updated capability status for the teamed systems.

Figure 2 shows a simple example of how the subsystem-to-function implementation works in practice. The availability of components, grouped into subsystems, is input via the data tags (yellow) to the left. Those availability values are separated and then logically combined to form the availability of the function. A final input (lower left) is a "virtual" entity; it is required to be "on" (the default) to satisfy the requirements of the function's availability logic but can be switched off in the event script.

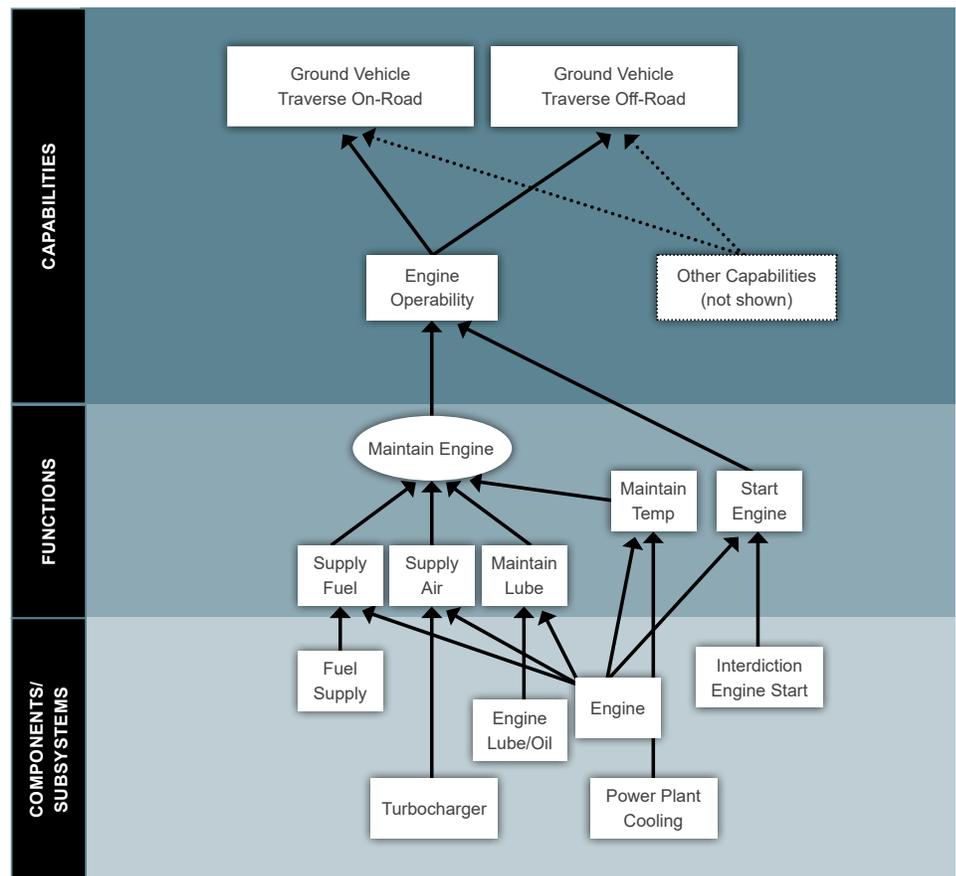


Figure 1: Simplified Functional Tree for Ground Vehicle Traverse (Source: Andrew Drysdale).

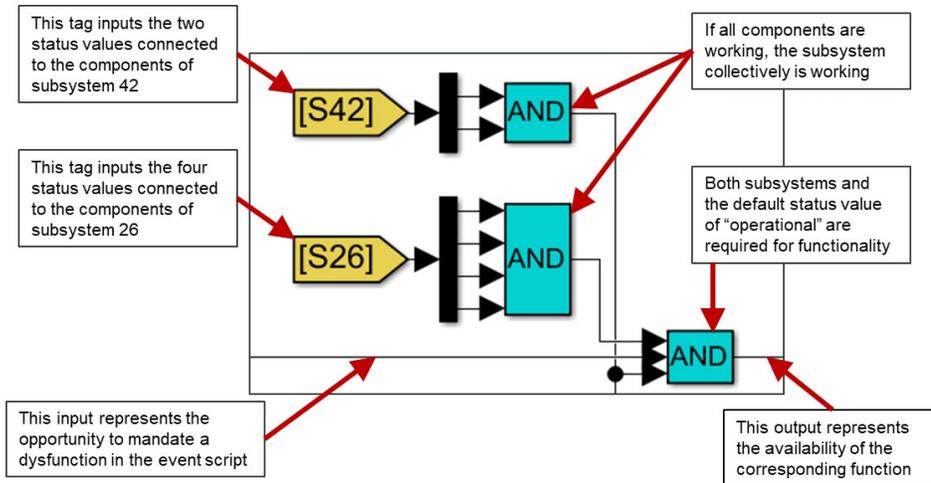


Figure 2: Example of Functional Tree Simulink Implementation (Source: Andrew Drysdale).

This gives the analyst the opportunity to disable a function (or subsystem or capability) without specifying which constituent is unavailable.

The event script is essentially the encoded narration of the modeled scenario. In other words, it provides the actions performed upon the actors. The script's simple format arranges information by column as follows:

1. Event ID: an arbitrary, unique number.
2. Time of event occurrence (dimensioned consistently with the status updater).
3. Narrative branch ID.
4. Event type: what level of entity is affected and whether its availability is gained or lost.
5. Object ID: identifies the entity affected within its level.

The script is read into the SCAP processor before execution and stored as a two-dimensional table; this allows editing the script (inserting or removing events) during runtime if the scenario requires that flexibility.

The “narrative branch” of a scenario assesses which combination of conditional statements is currently valid. Using narrative branching allows analysts to dictate that something in the scenario will occur *if* one or more conditions are met. Different paths that the scenario may take—depending on a random draw, a choice of initialization values, or other methods—are mapped out ahead of time. The event script will only recognize events that occur on the current branch. Narrative branching helps analysts build many closely-related scenarios in a batch and will allow stochastic modeling in the future. The transition logic that governs switching between branches is stored in the status updater, which is called at every time step in the scenario to check for a transition.

The status updater is the final input in a SCAP-based ATAC analysis. This is a code section unique to the specific scenario. It is where narrative branches are switched, nonbinary state values are calculated, and mission objectives are stored. It also measures mission completion or other evaluation metrics.

Using narrative branching allows analysts to dictate that something in the scenario will occur if one or more conditions are met.

The processing algorithm used for ATAC is itself quite straightforward. Each processing iteration represents one step forward through the scenario at a time interval specified by the analyst. At each time step, the event script is checked for a new occurrence. If one is found, the functional trees are re-executed. In either case, the status updater is called in order to record progress through the scenario. The scenario's timeline is played through this way until the end time or when an exit condition is reached.

The ultimate product of SCAP-based modeling is a time history of system capabilities. If the status updater is set up accordingly, it is also a verdict on mission completion or other objectives. For our development work, output consists of the histories of analyst-selected entities in scatterplots, with green corresponding to availability and red to dysfunction. A notional sample is shown in Figure 3.

## ADVANTAGES OF CAPABILITIES-BASED ANALYSIS

SCAP, especially as applied to teaming scenarios germane to ATAC, is well positioned to answer the DAL-related issues mentioned in the opening

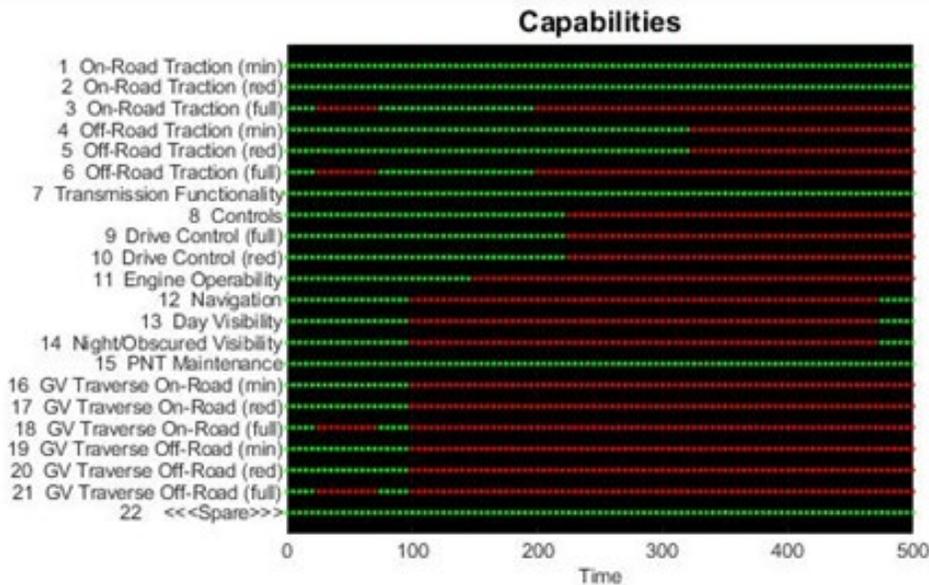


Figure 3: Output Plot Showing Status of User-Determined Capabilities (Source: Andrew Drysdale).

section. These advantages and other merits of the methodology are discussed next.

In contrast to the DAL-based paradigm, SCAP attempts to express the availability of every entity on every level of granularity as a binary value. By avoiding partial, probabilistic, or otherwise nonbinary availability values, the propagation of a dysfunction through the functional tree is made less ambiguous. (The availability of an indirectly affected entity switches from 1 to 0 instead of, perhaps, from 0.20 to 0.16.)

Additionally, functions and capabilities themselves are finely categorized and descriptive enough that their status is more informative than DAL outputs. (Losing the “traverse off-road at full speed” capability but retaining “traverse off-road at minimum speed” provides more salient information to the analyst than “assess a 0.4 mobility kill.”) Thus, the SCAP methodology represents a significant improvement in the ability to preemptively answer the “so what” question of how a certain damage

level affects the system’s remaining capabilities. This represents an important added value for various DAC analyses consumers.

The other drawback identified with DAL-based methodologies is their propensity for modeling the target system(s) in a vacuum, both in terms of separating from other battlefield assets and isolating from other events that affect the system’s operability. The SCAP methodology can respond to both senses of this problem.

One particular advantage of SCAP is in the way information is organized; it calls for each analysis to operate on a single, unified functional tree, which tends to emphasize high-level capabilities of the holistic team. Actors are considered as a single aggregated team from the beginning, instead of being modeled separately and then pasted together for modeling purposes. As a result, analysts are less likely to mischaracterize or entirely overlook the emergent properties, functional redundancies, and nonlinear capability changes that occur with teams of multiple actors.

The SCAP methodology represents a significant improvement in the ability to preemptively answer the “so what” question of how a certain damage level affects the system’s remaining capabilities.

Modeling the networking of a great number of interchangeable actors, such as a fleet of unmanned aerial vehicles, may be especially simplified by looking through the lens of the team’s capabilities as opposed to the status of individual systems.

When modeling a coherent narrative where the outcome of a threat encounter influences later event outcomes, SCAP methodology was very compatible with the sort of event scripting utilized to this point in ATAC development. A capability-based approach can even offer certain advantages. For example, decision logic in traditional analyses can become quite complicated when the relevant criteria distributes between multiple teamed systems. However, the SCAP functional tree serves as a labeled array of system states across the entire team, and the array remains available throughout scenario execution.

Thus, the logic becomes more intuitive to programming and verifying. Instead of requiring new ad hoc variables at each evaluation point, decisions can be defined to require input only from values already calculated when processing the

tree. This keeps decisions linked to the tree’s plain-language descriptions of the team’s states and capabilities and limits ambiguities as to why a scenario’s narrative branch is conditioned a certain way.

### SCAP’S PLACE IN THE SVL ANALYSIS TOOLBOX

It is important to note that SCAP methodology does not determine *whether* damage occurs due to a threat encounter but only what the capability losses would be if damage occurs. It completely abstracts the actor(s) into lists of capabilities and lower-level functional entities, the logical interdependencies of these entities, and their current states of availability.

Since a SCAP model does not generally carry the information required to “play” an encounter as a component-level vulnerability model, it mandates dysfunctions via an event schedule. In some types of analysis, a mandated event schedule is useful because it

controls and standardizes the input damage. In many others (particularly as associated with T&E support), however, part of the premise of the analysis is that component-level damage is not known beforehand. Thus, SCAP cannot replace component-vulnerability modeling, such as penetration or fire-initiation codes, and should be seen as occupying a different niche in the SVL analysis ecosystem.

One promising method where SCAP advantages might be leveraged to allow the interaction of models of different scope is shown in Figure 4. An engagement model or other means of setting the terms of a target-threat interaction are used to generate the parameters necessary for SVL modeling. This information is then fed to the ballistic-penetration model, cybermodel, or other means of determining component-level damage. A damage prediction becomes the input for a SCAP model (essentially becomes a single-line event script) that updates the system(s)

SCAP cannot replace component-vulnerability modeling and should be seen as occupying a different niche in the SVL analysis ecosystem.

accordingly. These updates are then fed back to the engagement model, which can then adjust its agents as appropriate and continue.

This method is far more feasible under a SCAP paradigm than with DAL-based methods because DAL output is too generalized to be useful to the engagement model. By contrast, capability-based modeling outputs exactly the type of capability losses that can inform how a high-level engagement

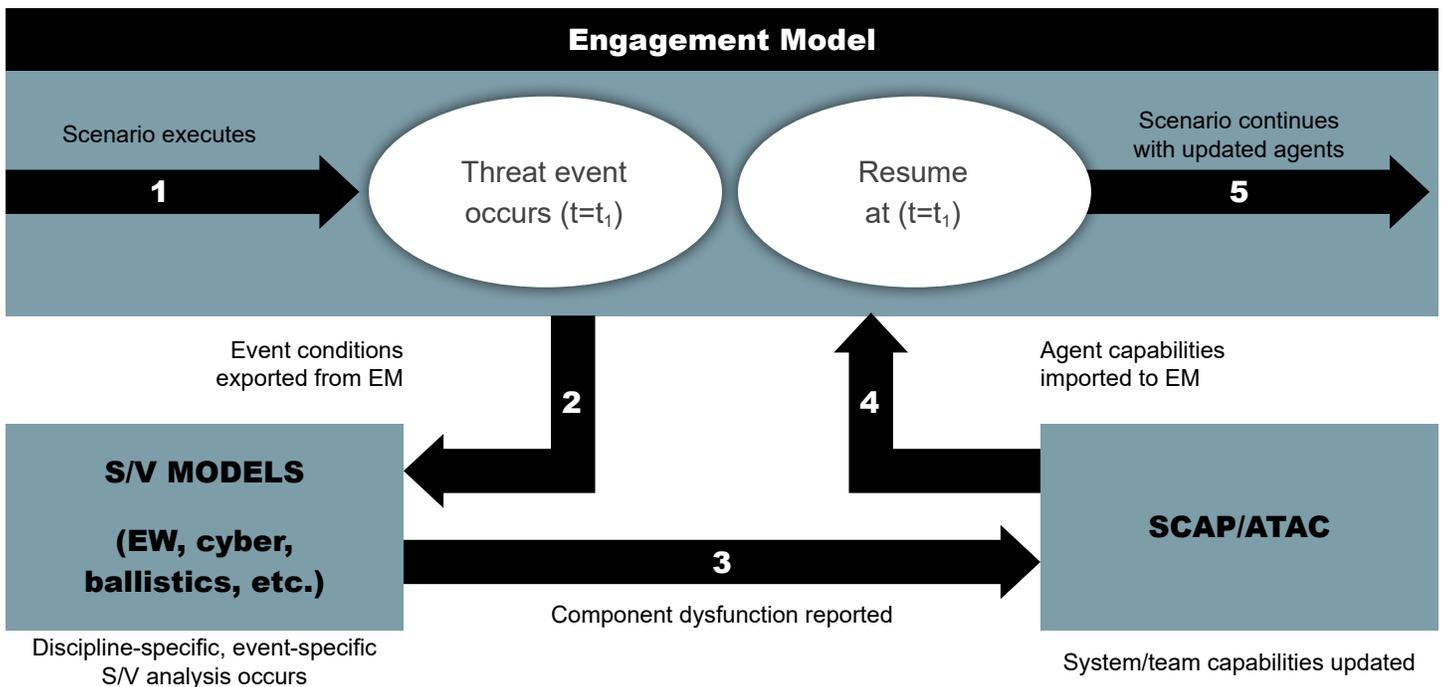


Figure 4: Integration of SCAP/ATAC With Component SVL and Engagement Models (Source: Andrew Drysdale).

model controls the actors for the remainder of the scenario.

## TEST CASE AND NEXT STEPS

Through the ATAC effort, DAC performed analysis of a hypothetical “route recon” mission that verified certain programming strategies in SCAP/ ATAC implementation and served as a methodology proof of concept. The teamed actors were a Bradley Fighting Vehicle (B-FiST variant) and a generic unmanned aerial vehicle (UAV) based on the RQ-20 Puma 3 AE. Functional trees and several event scripts were created specifically for the exercise. This test case was geared toward demonstrating that a SCAP-based analysis could process a series of contingent events as a unified, coherent narrative. As such, the event script mandated one of four damage outcomes to an initial threat encounter during the scenario. Each outcome, in turn, led to disparate capability losses later in the mission.

Mission success was assessed in the status updater in the team’s reconnaissance-related capabilities late in the scenario. As expected, the SCAP model successfully assessed different

levels of mission success based on the initial levels of dysfunctionality sustained. Event script variations for this exercise and associated changes in mission outcome are shown in Table 1.

To build on this early work, several initiatives are planned for FY 2020. First, the library of systems with populated functional trees will expand to include additional rotorcraft and artillery systems. Although the emergent properties of a team mean that a system cannot be fully “drag and dropped” into an ATAC analysis, building out SCAP input for individual systems is an effective way to partially prepare for future exercises. Second, the implementation of more complicated forms of narrative branching will be tested so that decision making can be shown in an operationally realistic context. Finally, DAC will determine the best way to incorporate SCAP/ATAC methodology into a larger program for addressing the analysis requirements of multidomain operations and other teamed-system engagement cases. Together, these initiatives will help position DAC to remain at the forefront of Army analysis as the battlefield further evolves. ■

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Table 1: Test Case Variations and Outcomes

TRIAL NO.	INITIAL DAMAGE	DOWNSTREAM CAPABILITY CHANGE	ASSET STATUS AT CHECKPOINT	OVERALL MISSION ASSESSMENT
1	None	No further loss	Fully operational	Fully successful
2	UAV operator incapacitated	UAV lost (ballistics)	UAV unavailable	Partially successful
3	Beyond-line-of-sight communications unavailable	UAV lost (electronic warfare)	UAV unavailable	Partially successful
4	Road wheels damaged	Team returns to base	Not applicable	Unsuccessful

(Source: 123rf.com)

## The Synthetic and Measured Paired and Labeled Experiment

# (SAMPLE) DATASET

## FOR SAR ATR DEVELOPMENT

By Benjamin Lewis, Theresa Scarnati, John Nehrbass,  
Elizabeth Sudkamp, Stephen Rosencrantz, and Edmund Zelnio

### SUMMARY

**D**eveloping automatic target recognition (ATR) algorithms for synthetic aperture radar (SAR) imagery is an important step toward effectively processing the amount of data created by SAR platforms. Allowing computers to efficiently extract the data from these images and return only relevant information dramatically accelerates the decision-making process. However, to effectively use popular machine learning algorithms for this task, a large quantity of training data is needed. Collecting and labeling data is prohibitively expensive, so obtaining the required quantity of data requires computer

simulation. This, in turn, introduces assumptions to the dataset that must be properly addressed. We have developed the Synthetic and Measured Paired and Labeled Experiment (SAMPLE) dataset to aid research in training networks with synthetic data for better generalization to measured imagery. The key feature of this data is that the computer-aided design (CAD) models used during simulation are carefully matched to electro-optical imagery that was taken during the SAR data collection. This removes much of the variation between simulated and measured data and leaves researchers free to investigate the underlying difference between the simulated and measured domains.

### INTRODUCTION

In today's world, large quantities of data are used to solve a number of problems. This data is often plentiful and inexpensive; high-resolution sensors and fast data links provide a constant stream of information for a variety of purposes. This has upended the balance between human processing power and available data present a few decades ago, creating an ever-increasing "pixels-to-eyeballs ratio." Because of this, it has become even more necessary to develop computer vision and processing techniques to intelligently distill this information for human consumption and decision making.

For imagery information, unifying decades of research in computer vision and extremely fast and parallelized computational resources has resulted in an effective toolset of machine-learning algorithms, such as convolutional neural networks [1] and recurrent neural networks [2]. These networks have driven fast advances in a host of fields; however, this requires a significant amount of data. Fundamentally, these networks fit a high-dimensional, nonlinear parametric function to the data. Without a sufficiently large and varied dataset on which to train, the training process will cause the function to overfit the data, resulting in poor generalization. In general, collecting and truthing data for training machine-learning algorithms can be expensive.

For SAR, a sensor of interest in military and civilian applications, data collection for research is especially cost prohibitive. Collecting airborne SAR images involves flying a radar on an aircraft, which naturally costs much more than simply taking images of random objects with a camera. The cost of acquiring airborne SAR imagery is most likely a key reason that the current state-of-the-art SAR research dataset, the Moving and Stationary Target Acquisition and Recognition (MSTAR) [3] dataset, is over 20 years old. It can be reasonably assumed that new datasets for SAR data will not be forthcoming with great frequency.

In the absence of SAR data collected in the real world, a machine-learning solution to the SAR ATR problem requires using simulated SAR imagery, which forms by computing how a radar pulse interacts with a computer model of a target. Because simulations approximate the real world, an image of the same target and the same parameters in both domains will be slightly different; we term this

Unifying decades of research in computer vision and extremely fast and parallelized computational resources has resulted in an effective toolset of machine-learning algorithms.

the “synthetic/measurement gap.” However, careful attention to simulation parameters and the fidelity of computer models can help reduce this gap and drive productive research into creating an ATR that can generalize to measured data.

The SAMPLE dataset [4] was designed to foster investigation in minimizing the gap between simulated and measured SAR imagery. While early research with this dataset has not conclusively solved this problem, we anticipate that access to this dataset by the wider defense community will accelerate research efforts. A portion of the dataset has been cleared for public release, and the entire dataset is available to employees of U.S. government agencies and their contractors. Data products include portable network graphics format images of the image magnitude and Matlab files with complex imagery data.

Due to space constraints, we present an overview of the dataset in this work and refer the reader to our published conference papers [4, 5] for an expanded view of the implementation details. Here, we will discuss the philosophy and motivation of the dataset and discuss some of the research

problems it was designed to address. The preparation of the dataset will be presented next, followed by a discussion on the fidelity of the dataset. We then list a few research areas in which the dataset has been applied and present plans to expand the dataset and conclusions.

## THE SAMPLE DATASET

As the cost of computation has decreased, it has become more feasible to use asymptotic methods in electromagnetic computational software to simulate the interactions of a radar pulse with a computer model. The SAMPLE dataset leverages this inexpensive computation to add a synthetic imagery extension to a portion of the MSTAR dataset. To create the synthetic imagery, we based the simulated SAR data on high-fidelity computer models of vehicular targets from the MSTAR dataset. These models were initially created during the MSTAR program; we added value by correcting errors, fixing surface normals, and leveraging modern standards and file formats. While models of more targets were available, several models were rejected due to lack of complexity or major missing parts. The remaining usable vehicle models are listed in Table 1.

Our primary goal in creating the dataset was to minimize the difference between the two realms of data. This enables investigating the gap in fidelity between the two domains that affects the real-world performance of ATR algorithms trained using simulated data. This gap is manifested in various ways, all which are products of the assumptions made when creating synthetic data. For example, the ground plane in simulated imagery is assumed to be flat, with a statistically rough surface, and empty of objects. This does not match the real-world conditions where

Table 1: Vehicles Included in the SAMPLE Dataset With Corresponding Serial Numbers

VEHICLE	2S1	BMP2	BTR70	M1	M2	M35	M548	M60	T72	ZSU23-4
SERIAL #	B01	9563	C71	OAP00N	MV02GX	T839	C245HAB	3336	812	D08

the ground consists of varying soil types and accompanying dielectric constants, exhibits elevation changes, and features rocks and plants. Simulation fidelity also suffers when using asymptotic electromagnetic simulation methods instead of rigorous but computationally impractical full-wave electromagnetic simulations. Furthermore, the simulated data is created using computer models of targets. These computer models, which may not perfectly match actual target geometry, are idealized by design. This, again, does not reflect properties of real targets, such as manufacturing variations, dents, or the presence of dirt. In order to overcome these differences, an ATR algorithm must correctly identify relevant features of the target (such as shape or pixel intensity) while ignoring imperfections, which is a challenging task.

Despite the inherent differences between simulated and measured data, there are many aspects that can be controlled. In particular, we focused on removing the differences in target articulation when creating this dataset. We also carefully minimized image

differences that are a function of data collection and image formation, such as the data collection parameters, pixel spacing, and image formation algorithm, by replicating the parameters used in the MSTAR collect when forming the synthetic images.

Because the appearance of objects in SAR images is highly correlated to the relative positions of all surfaces (e.g., vehicle doors and hatches), we made great efforts to articulate these models to match their position during the MSTAR collect. We used data about one instance (the serial number shown in Table 1) of each vehicle as the ground truth. Sources for this positional information included photographic documentation, such as the images shown in Figure 1, and textual information from the MSTAR program reports. An iterative process was used to closely align the model positioning with this truth information—a time-consuming task. Due to the small wavelength ( $\sim 3$  cm) of radar frequencies, it was necessary to check the position of surfaces at these sizes, such as equipment and small hatches,

in order to create an electromagnetic return consistent with the measured data.

## DATASET FIDELITY

The SAMPLE dataset exhibits good qualitative fidelity relative to the measured data. A visual inspection of randomly selected, measured images (shown in the top row of Figure 2) and corresponding synthetic images (bottom row) shows that the position, orientation, and amplitude of the vehicles in these images agree. While there are obvious discrepancies in the background, we presume that a successful approach to solving the synthetic/measurement gap problem will compensate. In any case, the nontarget area of an SAR image does not necessarily have any particular property or pattern. We believe that ignoring background information will help solve this problem.

To assess the dataset's fidelity from a neural network point of view, we applied the t-distributed Stochastic Neighbor Embedding (t-SNE) [6] visualization technique to the dataset. In creating this representation, we trained a



Figure 1: MSTAR Images Used for the CAD Models During the Model Preparation Phase (Source: U.S. Air Force Research Laboratory [AFRL]).

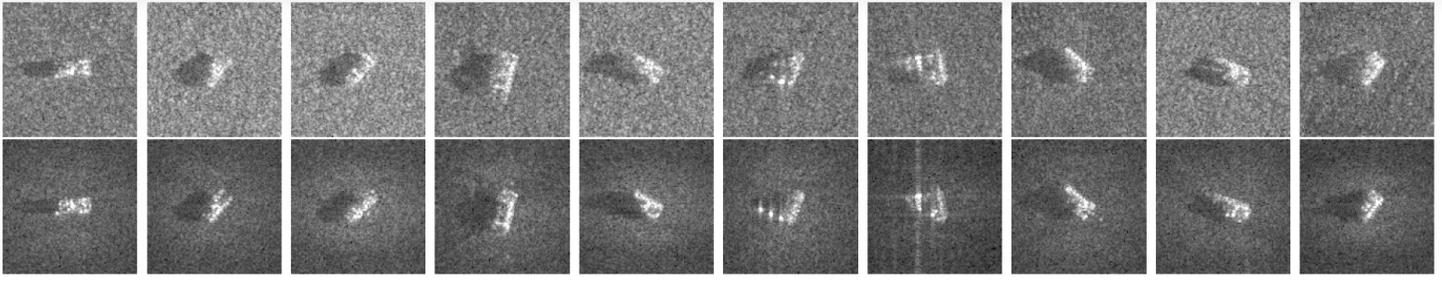


Figure 2: Randomly-Chosen Images of Each Vehicle in the SAMPLE Dataset, With Measured (MSTAR) Images (Top Row) and Corresponding Synthetic Images (Bottom Row). The Order of the Vehicles From Left to Right Matches Table 1 (Source: AFRL).

DenseNet [7] neural network on the measured images, then removed the last layer. Feature vectors for all images in the dataset were computed by evaluating each image using the trained network. The feature vectors were then presented to the t-SNE algorithm, which embeds high-dimensional points in a low-dimensional (two in this case) space. This transformation creates a probability space in which points proximal in high-dimensional space have a high probability of being close together in the representation space. The t-SNE algorithm does not have any notion of class type during its execution. Because of this, points from the same class are only represented near each other if their feature vectors are also close in Euclidean distance. Finally, we reassigned labels and data types to each point to produce the plots shown in Figure 3.

Because the feature vectors are based on a network trained on measured data, it is understandable that the representation of the measured data in Figure 3a is more clustered by class than the synthetic data in Figure 3b. This clustering is a good proxy for how well a classifier will perform. While the clustering for the synthetic data is less clearly defined, the joint graph (Figure 3c) shows that most instances of each vehicle—in both domains—cluster in the same two-dimensional space, with some exceptions. However, it appears that the measured and synthetic portions for each class, while adjacent, are somewhat disjointed. Nevertheless, this is a promising result, suggesting that it is possible to transfer information between the domains in a way that both sets of data can be separated by a network.

This separability is not so easily teased out by a neural network, however, which leads us to the current problem. Neural networks, such as DenseNet [7], easily classify MSTAR imagery when trained on data at one elevation and tested on a similar elevation. The average 10-class accuracy, shown in Figure 4a, hovers at a near-perfect level. However, a network trained completely on our synthetic data and tested on measured data suffers a dramatic performance hit, as in Figure 4b. Research is ongoing to bridge this gap.

## APPLICATIONS

The SAMPLE dataset has been used for basic research in a number of publications since its inception. These papers showcase some of our efforts to solve the problem of using synthetic data to train a generalizable machine-learning algorithm for ATR. Some of these approaches include

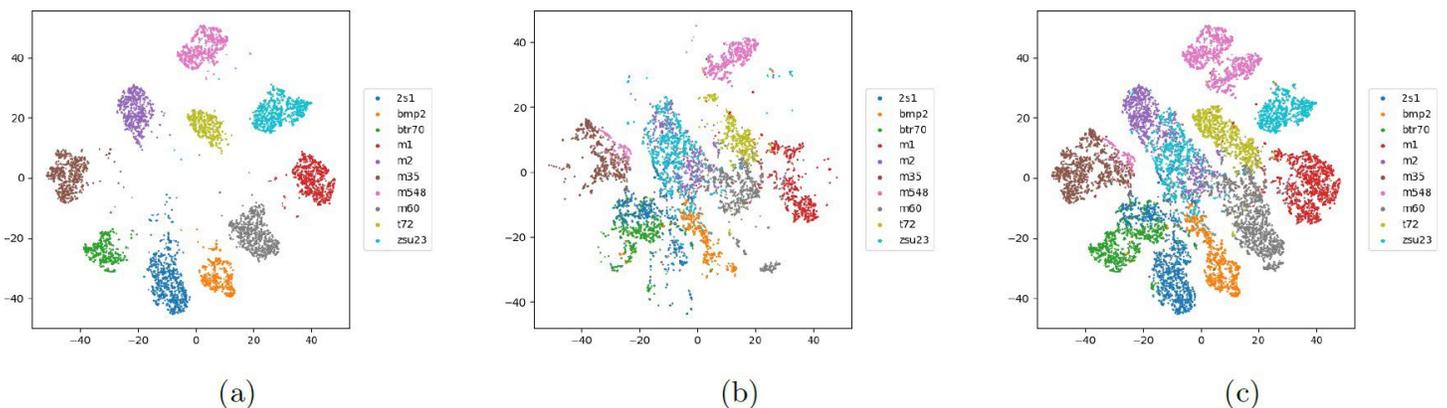


Figure 3: A Two-Dimensional Visualization of the Measured (a) and Synthetic (b) Portions of the Dataset, Along With Two Portions in One Graph (c) (Source: AFRL).



Figure 4: Confusion Matrices for a DenseNet Network Trained and Tested on Measured Data (a) and Trained on Synthetic Data and Tested on Measured Data (b) (Source: AFRL).

using generative adversarial networks [8] to make the synthetic data look more realistic [9, 10], using image preprocessing techniques to reduce the variation between the image domains [11], using transfer learning approaches to blend the two datasets [12], and using Siamese networks to learn information about both domains [13]. While none of these approaches have completely solved this issue, they collectively indicate possible successful approaches to this problem.

In a broader context, we defined a set of challenge problems that we hope the dataset will address (see Lewis et al. [4]). These challenge problems include (a) training an algorithm entirely with synthetic data to completely generalize to measured data, (b) training with a very limited amount of data from each of the 10 classes, and (c) training with measured data from a subset of the

classes. While challenge problem (a) is the most difficult and most rewarding problem of the set, problems (b) and (c) prove interesting as well and encourage the use of existing measured data in conjunction with the ability to create large amounts of simulated data. We have also set forth a basic machine-learning approach to these challenge problems [11].

Beyond machine-learning applications, the synthetic portion of the dataset may also serve as a second standalone dataset to complement MSTAR. Many techniques for classification [14], feature extraction [15], image enhancement [16], and image segmentation [17] have been developed over the years and validated using the MSTAR dataset. In future research, such techniques may use the synthetic imagery as a validation set.

## FUTURE WORK AND DATASET EXPANSION

While SAR is an excellent all-weather sensor, additional information from other sensor modalities may also be useful. The SAMPLE dataset does not represent the final state of our dataset creation efforts, especially given the availability of open-source tools such as Blender [18] to create high-fidelity simulated camera imagery from the models we already have. This expansion to another sensor will foster research efforts in multisensor target classification and data fusion. We do not plan to limit this dataset solely to MSTAR imagery if other appropriate data sources can be found.

Unfortunately, real-world electrooptical (EO) imagery of the MSTAR targets is unavailable, except for the small number of truthing images used to determine the appropriate target articulations.

Extensions to the dataset for the MSTAR targets will be limited to synthetically-generated camera imagery, which still has utility. For example, experiments may leverage synthetic EO data and SAR data to train an ATR algorithm, which can then be tested on a held-out set of EO data and measured SAR imagery.

We also hope to identify other sources of measured SAR data with a rich set of accompanying EO data. Augmenting such a dataset with simulated EO and SAR data would be ideal to further study multitarget classification using synthetic data. Because truthing the CAD models is so time intensive, it would also be interesting to reduce the truthing fidelity to study how much the target articulations must match in order to produce good results using techniques developed with the SAMPLE dataset. Other interesting properties of this type of expansion include imaging resolution, image formation algorithm, new targets, and more challenging environments for the targets.

Aside from expanding the dataset, our work in using machine learning to bridge the gap between synthetic and measured data will continue, with new work building on many of the ideas mentioned in Section 4. Ideas in this direction include leveraging adversarial network attacks to increase network robustness, investigating the inherent interclass differences between target classes, mixing hand-designed descriptors and machine learning, and using neural networks to leverage more information (such as phase).

## CONCLUSIONS

We have presented a brief overview of the SAMPLE dataset as a supplement to the implementation details presented in earlier papers [4, 5]. Currently, this dataset consists of measured SAR imagery from the MSTAR dataset and

synthetic imagery designed to match these images in image formation parameters and target articulation. By studying the remaining differences between the two sets of data, we anticipate that researchers will be able to discover ways to train an ATR system on synthetic data that can generalize to measured data. ■

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## BIOGRAPHIES

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(Source: 123rf.com)



# FLIGHT STANDARDS

## for UAS in the National Air Space

By Shawn Nelson

### INTRODUCTION

**P**roliferation of unmanned aircraft systems (UAS) for military operations has proportionally increased the number of pilots trained to operate these systems. While there are UAS hands-on testing standards in the military, the thoroughness in manned proficiency checks is not reflected in UAS standards and is nonexistent in Federal Aviation Administration (FAA) regulations.

Any certified, manned pilot will say that a hands-on practical test, more commonly referred to as a “checkride,” can make even a competent and proficient pilot anxious, nervous, and tense. Evaluating against a set of standards will make a seasoned pilot feel the same stressors felt by a new pilot. If the pilot fails to correctly complete a task to standard, he or she cannot remain certified until retrained and reevaluated. Flight standards for manned systems have produced certified pilots with dependable, demonstrated piloting

capabilities. This has been the way of aviation for almost a hundred years, that is, until UAS emerged.

UAS flight control methods vary as much as airframes. Examples like the MQ-1 Predator, which allows the use of a hybrid of manual stick-and-rudder and autonomous flight control, and the larger RQ-4 Global Hawk, which is entirely autonomous (to follow the operator’s preset programming), are just two of the many possible forms of control used today.

While the focus of this article is on manual flight control and standards, the need for programming and mission analysis standards may be even more crucial in the military, where automation is constantly enhanced and preferred by commanders. The predictability of mission programming and the decreased reliance on physical skill make this an attractive option.

Experience has shown that repeated synthetic aperture radar runs flown

manually are inferior to programmed runs, which ensure that airspeed, altitude, heading, and start and end points are duplicated every time for consistent imagery comparisons. The increase of this automation allows easier standards for flight personnel (thus, a higher percentage of operators are likely to successfully complete training) and a reduction in flight control human error incidents. These are both highly desirable outcomes of autonomous flight; however, they cause complacency, which will be discussed later in this article.

Since 2016, the FAA has allowed the public to fly small UAS (sUAS) (under 55 lb) in the National Airspace without a lengthy Certificate of Authorization process. Currently, UAS can be flown for research and development (R&D) or recreational purposes, with virtually no pilot testing required by the FAA. The Army has standards for their small UAS, such as the RQ-11 Raven, a 4-lb, fixed wing drone. Yet even these requirements

pale in comparison to those of both FAA and military manned aviation. Think a 4-lb flying camera cannot do any harm? The following examples highlight the contrary, as accidents happen. Therefore, flight standards need to be set.

- **July 21, 2016:** Doug and wife Rochelle from Utah were struck by a “drone” while posing for wedding photos. Video from the incident shows the quadcopter, weighing ~3 lb, striking Doug in the head. As the drone tumbles to the ground, you can see that Doug was also knocked down but not seriously injured [1].
- **2017:** A commercial airplane was hit by a drone while approaching Quebec City, Canada [2].
- **January 2019:** New Jersey’s Newark Liberty International Airport experienced flight disruptions after a drone was sighted at 3,500 ft (FAA regulation is 400 ft above-ground level [AGL] max) near Teterboro Airport [3].
- **September 6, 2013:** Roman Pirozek, Jr., of Queens, NY, was killed when his remote-controlled (RC) helicopter struck him, the rotors slashing his head and neck. Roman was attempting an aerobatic maneuver with the RC helicopter when he was struck and later died of his injuries [4].

## REGULATIONS AND THE NEED FOR HANDS-ON-TRAINING

UAS regulation is in its infancy. Currently, a Part 107 sUAS Remote Pilot Certificate is obtained by taking a written test only, without hands-on testing. The military has a comparable written testing program with limited or no flight tasks for their sUAS. The Part 107 certificate demonstrates that the regulations, operating requirements, and procedures for safely flying

drones [5] are understood. But all risk-management evaluations for UAS operations, especially in a military context, should consider standardizing a hands-on practical testing method because memorizing a written test by rote memory does not equate to verified flight proficiency.

For example, ask anyone who does not have a driver’s license how to drive a car, and they can tell you about gas, steering, brake, clutch, turn signals, stop lights, speed limits, etc. This is the understanding phase of learning, with the individual parts understood. But blending them together is not as clear, nor is the physical requirement of coordination.

Now have them drive the car for the first time. As action, sequence, and timing become required, individuals realize that the process is much more than rules and theory as the car stalls for the 10th time or they blow through another stop sign. A lack of comprehension and correlation makes these new drivers dangerous to themselves and others until experience is gained. If we demand this of drivers, why not military UAS operators?

The intent of standardization is not to make our UAS operators “walk uphill in the snow” like their manned parents did; it is to produce and maintain a proficient operator that can support the commander’s mission with confidence. There are perceived and actual differences in standards required for UAS licensing. If we are to have manned and unmanned aircraft share the same sky, then consistent and reasonable standards should apply to both.

Without formalized training on the operating system, a UAS operator will not have as complete a skill set to avoid accidents as those with training. This training enhances aeronautical decision

making (ADM), the systematic approach to mental processing used by aviation personnel to consistently determine the best course of action for a given set of circumstances [6].

Good ADM allows the operator to fly safely while completing the mission. Knowing the limits of the system (i.e., line-of-sight uplink and downlink connection, battery duration, fuel burn, etc.) allows precise flight planning that reduces the chances of exceeding a limit and possibly losing the aircraft. Lost link planning is often the last thing inexperienced operators think about. Flight planning that includes lost link contingencies is critical in preventing the aircraft from returning to home base along a path that may have obstacles. If system limitations preclude preplanned lost link routes, then planning the entire flight to ensure zero obstacle interference between the home station and aircraft is a must.

When discussing actual flight controls, there are generally two types of interfaces—manual control and preprogrammed control. Preprogrammed control is plotting a route and altitude and sending it on its way to fly a route autonomously. Should standards apply to this type of control? Absolutely! While the software does the actual flying, the operator must still know the software and its capabilities and limitations. If the operator selects a wrong setting (selecting mean sea level instead of AGL, kilos instead of pounds, or mph instead of knots), the aircraft may end up flying somewhere unplanned. Unplanned flight means uncontrolled flight, a risk the U.S. Department of Defense (DoD) and FAA should work to mitigate. Currently, the FAA only requires reporting of uncontrolled flight, even in restricted airspace, and nothing else.

Current technologies allow UAS to fly entire missions autonomously, without

input from the operator. More expensive systems provide collision avoidance from stationary objects and auto return to the home station in case of unprogrammed deviations encountered during flight. If overreliance of systems and a lack of understanding autonomous logic are not mitigated, complacency is almost ensured as a by-product with this level of autonomy. Complacency has no place in military missions.

It is not enough to simply plot a line between two points and hope for the best. Route reconnaissance identifies hazards not seen from the launch location (i.e., trees, power lines, buildings, terrain, etc.). A well trained operator knows that route reconnaissance is a must. The question is, if it is not a standard, who is responsible when the UAS becomes a lost link and flies into the side of a hill on its way back to the home station?

Comprehensive standards, which identify appropriate actions to minimize flight logic programming errors and increase system knowledge, are effective in assisting the operator with safe flight practices and mission accomplishment.

How can hands-on training be standardized to help military operators increase their operational experience? As stated, the software and hardware of UAS systems vary greatly from platform to platform. This wide array of differing interfaces makes it almost impossible to establish standardized flight control evaluation from a hand controller perspective. Each system requires a unique method of control and evaluation. End-state maneuvers should be trained and evaluated and focus on completing the maneuver to a standard equal across all platforms. This approach will also work for preprogramming.

## DEVELOPING STANDARDS

Developing a proficiency standard should include the task, conditions, and standards to accomplish the task. These are defined as follows:

- **Task** – The task is the desired end state; it is the point of the maneuver.
- **Conditions** – Conditions set the stage for accomplishing the task to include varying ways to evaluate the task, prerequisites, and equipment needed.
- **Standard** – The standard is a detailed description of the criterion required to accomplish the task.

There is often more than one way to accomplish the desired end state. While not every possible method can be covered, the detailed standards should provide someone new to the task a clear idea of how to successfully complete the task. Two example standards follow (Figures 1 and 2).

This results in the aircraft being flown a full 360 degrees. In flying four different directions relative to the operator, visual perspective is changed. Correlation between what is seen, and aircraft input, can be confusing at first. While left and right always remain the same

EXAMPLE 1 – DIRECTIONAL, DIAGONAL SIDE BOX	
<b>TASK</b>	Directional, diagonal side box.
<b>CONDITION</b>	Given UAS system with manual control or compatible simulator, successful completion of simple, diagonal side box task.
<b>STANDARD</b>	<p>Beginning at a corner of a marked box on the ground, adjust altitude up or down while flying to the next point of the box. The change in altitude should be a coordinated descent or ascent along a straight line between points. Upon reaching the second point, turn the aircraft 90 degrees to face the next point while maintaining altitude before proceeding. Repeat this two more times until the aircraft has returned to the start point.</p> <ul style="list-style-type: none"> <li>• Maintain aircraft <math>\pm 1</math> ft of diagonal line.</li> <li>• Maintain heading <math>\pm 5</math> degrees.</li> <li>• Maintain speed <math>\pm 5</math> kn.</li> </ul>
<b>ILLUSTRATION</b>	

Figure 1: Diagram of an Example Standard – Directional, Diagonal Side Box (Source: Shawn Nelson).

EXAMPLE 2 – IN-LINE PIROUILLE	
<b>TASK</b>	In-line pirouette.
<b>CONDITION</b>	Given UAS system with manual control or compatible simulator.
<b>STANDARD</b>	<p>From a start point, fly in a straight line to the finish point while spinning the aircraft 360 degrees. Begin by setting a constant yaw rate, beginning the spin.</p> <p>NOTE: The slower the yaw rate, the easier it is to control the aircraft straight across between points.</p> <p>As the aircraft spins, apply directional control toward the finish point relative to the aircraft's orientation (i.e., forward if the point is off the nose, aft if it is behind it). Because the aircraft is spinning, directional control will have to be constantly rotated opposite the spin at a rate that compensates for the spin.</p> <ul style="list-style-type: none"> <li>• Maintain altitude <math>\pm 2</math> ft.</li> <li>• Maintain aircraft <math>\pm 2</math> ft of course centerline.</li> <li>• Maintain speed at 3–5 kn.</li> </ul>
<b>ILLUSTRATION</b>	

Figure 2: Diagram of an Example Standard – In-Line Pirouette (Source: Shawn Nelson).

for the aircraft itself, as the aircraft returns toward the operator, visually, left and right have now swapped. An inexperienced operator will struggle with correct inputs, lacking practice and muscle memory for flying error free from a reverse perspective.

NOTE: Turning your body in the same direction the aircraft is flying will reduce reverse perspective confusion. While this can alleviate reverse perspective confusion, it requires the operator to stand.

A modified and easier version of this is to maintain one heading throughout the box, making no turns at the points.

Once learned, multiple pirouettes can be made along a given line, reversing direction after each 360. The control touch required to execute this maneuver requires constant adjustment as opposed to intermittent course correction normally required to fly a straight line. Being able to make constant control input while still maintaining situation awareness will facilitate better control in less-than-

optimal conditions like high or gusty winds.

Are these maneuvers necessary in completing normal flight for military missions? Not likely. Will they enhance the physical motor skills of the operator? Most definitely. When practiced and completed to the given standard, military operators learn competence and confidence in the system and their own abilities. Through muscle memory learned by repetition, cognitive processing is reduced when maneuvers become second nature. This allows faster recognition of emergencies and less time in initiating a response. Trying to remember which way the stick needs to be deflected for a left bank when the UAS is facing 90 degrees to the right is not acceptable during a time-critical maneuver.

## AERONAUTICAL DECISION MAKING

Through improving knowledge and hands-on skills, ADM will also improve. While better if taught, ADM is also learned through experience and is essential for safe flight. The operator, aircraft, environment, and mission are parts of any situation. When there is an event change that affects the situation, two responses are immediate—skills and headwork. Not only does practiced control touch allow positive skills response, but it can also reduce stress and facilitate better attitude management. Inadequate skills or headwork results in mishaps [6].

For example, an operator, having practiced the in-line pirouette maneuver to proficiency, is asked to fly a mission on a windy day. Looking at the weather report, the operator can determine that the reported winds and gusts do not exceed his or her abilities for the first 2 hours. Based on experience,

the operator is confident that the level of control input (constant correction) required to complete the mission is similar to the in-line pirouette maneuver. After that, the winds will become stronger and exceed the proficiency level to safely control the aircraft. The operator decides to land 30 min prior to the increased winds to ensure no mishaps occur.

Without having flown the maneuver, the operator might have no idea of the workload involved in constant correction flight or the level of skill needed to attempt such a flight. But having flown to the standard and being proficient at it, the operator can better recognize his or her limits and abilities and those of the aircraft, environment, and mission. This results in safe decisions and allows job completion and ensured aircraft safety.

The example also highlighted the pre-mission risk assessment. The military operator can prevent accidents before they happen by using a 5-step risk analysis process: (1) identify the risk, (2) analyze the risk, (3) evaluate the risk, (4) implement controls, and (5) monitor the risk. This risk mitigation process is taught to all personnel in the military and is integrated into everything done. No vehicle, ship, aircraft, satellite, or piece of equipment in the military is moved without a risk assessment that has been reviewed by the proper risk authority who will go/no go the mission based on an acceptable level of risk.

In order to maximize this process, a sound knowledge base is imperative, including, but not limited to, system knowledge, system experience level, weather, Notice to Airmen, Air Traffic Control coordination, mechanical status, and human condition. By identifying weak or dangerous mission components, control measures can be developed and implemented. Landing 30 min prior to

worsening weather is an example of a control implemented prior to mission start to help minimize the potential for a mishap.

## CONCLUSIONS

Military flight standards must be tougher, more rigid, and more focused than those of the FAA due to the increased level of risk that military personnel are exposed to as compared to the average civilian pilot. Because standards ensure flight safety and protect human life, UAS standards must improve to include, at a minimum, testing to demonstrate UAS flight proficiency. Too often, corrective action for known safety issues is delayed until after loss of life or media embarrassment. Military UAS flight standards must be proactively strengthened to produce certified pilots who have demonstrated abilities to successfully operate and thus yield more controlled and higher quality military UAS operations. The responsibility for proficiency must not be solely an individual duty.

Until the DoD or FAA mandates required maneuvers for evaluation, business opportunities exist for corporate and private businesses to develop training programs targeted at differing control interfaces. Industries performing R&D on UAS can quickly and easily test their systems. However, this ease comes with the risk that an unskilled operator can still cause damage or even injury or death by operating without standardized piloting requirements. Paramount in training programs is maintaining the focus on operator improvement and flight safety.

Each chosen standard maneuver should be tailored to the individual UAS being flown and experience levels of the operators. For example, motorcycle riders have riding courses ranging from the rider who has never sat on a bike

before, to off-road riding, to track racing. No less thought and effort should be made for remotely-piloted or automated UAS's.

Unmanned aviation is here to stay and will continue to be a critical technology for the DoD. As its versatility continues to expand, so will the R&D and associated testing. Establishing standards is not designed to make life harder but assist in accomplishing the mission successfully and safely. ■

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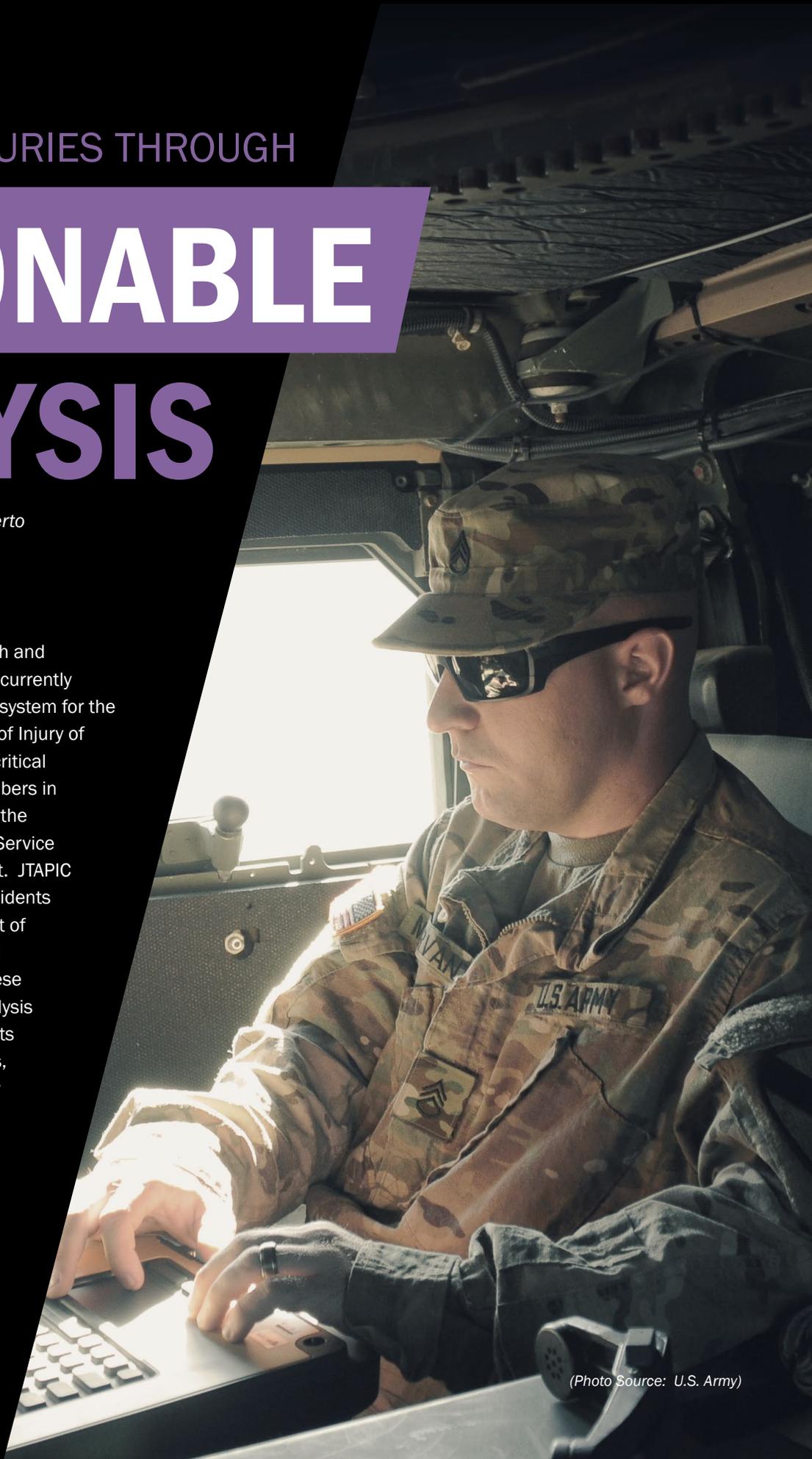
PREVENTING INJURIES THROUGH

# ACTIONABLE ANALYSIS

By Amy E. W. Bednar and Lindsay Liberto

## INTRODUCTION

**T**he U.S. Army Engineer Research and Development Center (ERDC) is currently developing a new online collaborative system for the Joint Trauma Analysis and Prevention of Injury of Combat (JTAPIC) Program to meet its critical mission goals to support Service members in theater. JTAPIC's mission is to enable the prevention or mitigation of injuries to Service members in the deployed environment. JTAPIC and its partners examine deployed incidents and accidents in the combined context of intelligence, medical, operational, and materiel viewpoints. By combining these four multidisciplinary areas in the analysis process, JTAPIC provides advancements and information for equipment, tactics, techniques, and procedures in theater and feedback to the acquisition process. For example, "modifications and upgrades have been made to vehicle equipment and protection systems, such as seat design, blast mitigating armor, and fire suppression systems.



(Photo Source: U.S. Army)

Combatant commanders have altered tactics, techniques, and procedures in the field as a result to the incident analyses and near real-time feedback on threats provided by the JTAPIC Program” [1]. This article discusses JTAPIC, past projects, and the new Web-based system currently being developed. Figure 1 is a screenshot of the new JTAPIC public Web site.

## BACKGROUND

The National Defense Authorization Act for Fiscal Year 2006, Public Law 109-163 [2], provides that the “Secretary of Defense shall designate an executive agent to be responsible for coordinating and managing the medical research efforts and programs of the Department of Defense (DoD) relating to the prevention, mitigation and treatment of blast injuries.” DoD Directive 6025.21E [3], in compliance with Section 256 of Public Law 109-163, “designates the Secretary of the Army ... as the DoD executive agent ... for Medical Research for Prevention, Mitigation and Treatment of Blast Injuries” and describes the responsibilities. JTAPIC has supported the executive agent for DoD Directive 6026.21E since 2006.

The JTAPIC charter [4], signed by the Secretary of the Army, designated JTAPIC as a permanent program effective 1 October 2012 to “assist the DoD Executive Agent in fulfilling its designated responsibilities and function related to medical research for the prevention, mitigation, and treatment of blast injuries....The mission of the [JTAPIC] Program is to facilitate the collection, integration, and analysis of injury outcome, materiel performance, and operational and intelligence data to improve the understanding of our vulnerabilities to threats and enable the development of improved protective



Figure 1: Screenshot of the New JTAPIC Public Web Site (Source: JTAPIC).

equipment; vehicular equipment; and tactics, techniques, and procedures that will prevent and/or mitigate combat injuries.”

## PARTNERS

JTAPIC, led by the Program Management Office (PMO), is a partnership between DoD intelligence, operational, medical, and materiel development communities that collects, integrates, and analyzes injury and operational data. The

JTAPIC is a partnership between DoD intelligence, operational, medical, and materiel development communities that collects, integrates, and analyzes injury and operational data.

materiel partners are PdM Infantry Combat Equipment, Program Manager Soldier Protection and Individual Equipment (PM SPIE), and U.S. Army Combat Capabilities Development Command – Data Analysis Center (CCDC DAC). The operations and intelligence partners are the Combat Incident Analysis Team (CIAT), National Ground Intelligence Center Combat Incident Analysis Division (NGIC/CIAD), Marine Corps Intelligence Agency, and Marine Corps Combat Development Command – Operations Analysis Directorate. The medical partners are the Joint Trauma System (JTS), Naval Health Research Center (NHRC), Armed Forces Medical Examiner System (AFMES), and U.S. Army Aeromedical Research Laboratory (USAARL). Figure 2 shows these partners in JTAPIC’s logo.

After the occurrence of a combat event, personal protective equipment (PPE), ballistic fragmentation evidence, threat assessments, and battle damage assessment of vehicular equipment are conducted and collected, along with operational data. At the same time,



## PAST PROJECTS

### **Current Operation Incident Report (COIR)**

The COIR is a detailed operational and injury report of recent incidents where U.S. Service members were injured while in contact with enemy forces. Once an event occurs, JTAPIC's CIAT collects operational/intelligence and casualty information. The information is integrated with any available medical or materiel data points to give a detailed picture of the casualty-causing event within the appropriate operational context. This product provides timely and relevant knowledge to customers and partners who utilize JTAPIC's analysis approach for decision support and provides combatant commanders near-time, holistic, after-action reporting to improve future mission planning.

### **Data Support for the Office of the Secretary of Defense**

This data-only product provides a limited dataset covering dismounted U.S. military combat casualties incurred from January 2011 through May 2017. The data comes from JTAPIC-integrated databases and provides analyzed data detailing when and where casualties were received, inflicting weapons, engagement ranges, distance from blast devices, and specific injuries incurred, when available. It also provides general casualty demographics data, including branch of service, service component, rank, gender, primary and duty military occupational specialty, and unit of permanent assignment.

### **U.S. Army Tank Automotive Research and Development Center (TARDEC) Occupant Protection Study**

This ongoing multipart analysis product (currently in phase 8 of 9) provides TARDEC with information on accidents

(collision, rollover, and collision with rollover) and combat casualties sustained in ground vehicles from 2010 through 2015, with a primary focus on occupant survivability. The findings of these studies will be used by TARDEC in developing an overarching crash and rollover standard to advance training, safety, and survivability for Stryker; mine-resistant, ambush-protected; family of medium tactical vehicles; and high-mobility, multipurpose wheeled vehicle platforms.

### **Blast Injury Prevention Standard Recommendation**

The analysis request was for the Blast Injury Research Coordinating Office (BIRCO). The lead partner for the request for information was NHRC, and the participating partners were NGIC/CIAD, CIAT, AFMES, CCDC DAC, and JTS. BIRCO needed to identify and prioritize the development of a Blast Injury Prevention Standards Report (BIPSR) based on real-time injury data. BIRCO was performing a reprioritization of blast injury types remaining in the BIPSR process queue. The analysis product showed the total frequency of combat blast injuries and total frequency of those injured from 1 January 2013 through 31 December 2015. Blast injury was defined. The frequency and proportions for each of the customer specified body regions, body subregions, and injury type were provided.

### **Improvised Explosive Device (IED) Casualty Trends**

The analysis request was for COL Nancy Parson, Director, Patient Care Integration, Office of the Surgeon General, for a briefing to the House Armed Services Committee. The lead partner for the request for information was NGIC/CIAD, and the participating partner was CIAT. The product details how IED casualties and incidents are

reported, the number of IED casualties from 2014 to 22 December 2016, and injury trending in IED casualties.

## JTAPIC INFORMATION AND COLLABORATION SYSTEM (JINCS) ONLINE SYSTEM

ERDC is developing JINCS, an online system that will facilitate rapid turnaround analyses leading to prompt and meaningful improvements in equipment, tactics, techniques, and procedures in theater and the acquisition process. JINCS will be hosted on the nonclassified internet protocol router (NIPR) and secret internet protocol router (SIPR) networks. The collaborative system will contain three main modules: (1) the RFI tracking and management system, (2) the product library, and (3) the database. JINCS will be available in stages beginning mid fiscal year 2020.

All of the JTAPIC resources, with limitations based on permissions, will be available once a JINCS account is obtained. JINCS accounts are available to DoD employees and contractors with a CAC utilizing the DoD-wide public key infrastructure certificate. Registering for an account is quick, easy, and straightforward. New users should go to the JTAPIC home page and follow the link to "Login" and then "Register for an Account."

## RFI MODULE

The RFI management module provides customers the ability to submit an RFI and track the progress made on their RFI. The RFI management module allows customers, PMO, and partners to track the complete life cycle of an RFI. The RFI management system will include a metrics system to track all tasks and record the time spent on each step of an RFI to facilitate performance improvement. Customers, PMO, and

partners can view information on an RFI including progress, current tasks, and any future steps necessary to complete it. Figure 3 is a screenshot of the general screen for a completed RFI.

To submit an RFI, a customer completes the analysis request submission online form in JINCS. After submission, the information will be reviewed by the JTAPIC partnership. A JTAPIC project manager (PjM) will be assigned to the RFI and may follow up with the customer about specific questions or to address obvious limitations.

The RFI will fall into one of the following four processes:

1. The request has already been answered from a previous JTAPIC project. Pending approval, the associated product will be released to the customer and justification recorded.
2. The request does not fall in the scope of JTAPIC and will be redirected to the appropriate organization, with the reasons for

any denial/redirection recorded.

3. Parts of a request can be answered while other parts cannot. In this case, the PjM will discuss portions of the request that can be answered and reasons for JTAPIC's inability to answer other portions of the original request.
4. JTAPIC and the partners begin developing and analysis product in response to the RFI.

If the RFI falls within the mission scope of JTAPIC, the JTAPIC partners hold a teleconference with the customer so the customer can communicate to the analysts exactly what information is needed. The analysts can describe the type of data available, type of analysis that can be provided, and expected time for a finished product. Once the teleconference has occurred, the request is processed by JTAPIC partners to identify key tasks and milestones, and a detailed schedule is completed and communicated. The customer can view the progress at any time using the tracking system in JINCS. If any issues

arise that occur as part of the analysis that affects the scope or timeline of the request, customers are notified by the PjM or PMO. Upon completion, the customer receives an email with a link to the analysis and/or a briefing to discuss the results and review the analysis product. The product will be uploaded in the appropriate product library and subject to any agreed-upon limitations for release or dissemination.

## PRODUCT LIBRARY

The product library is a repository of past JTAPIC products as well as products created by JTAPIC partners submitted for inclusion. Determining if a product can be viewed is based on privacy settings and user role and permissions. The library contains a variety of analyses and answers to questions relating to the JTAPIC mission. The products use a hierarchical tagging system to allow users to find related products in an easy and effective manner. The product library allows users the ability to view information on all public products within the system and download the product (with permission) to their local computers. The product library can be accessed on the left-hand menu in JINCS. Products will be housed on either the SIPR network or the NIPR network, according to classification.

JTAPIC ensures actionable information discovered within the JTAPIC partnership activities is shared as broadly as possible, except where limited by law, policy, or security classification. Those data and analysis products produced are communicated in accordance with DoD Directive 8320.02 [6].

## JINCS DATABASE

ERDC is in the process of designing and developing a database system to connect the disparate systems, along with subject matter expertise from the partnership for intelligence, operational,

RFI: -U Stryker Family of Vehicles: Combat Outcomes in Iraq and Afghanistan, 2003 - 2013      Status: Complete

General    Team    Discussion    Time Estimate/Schedule    Documents    Partner Comments    Customer Communications    Review    Approval    Questionnaire

**Title**  
Stryker Family of Vehicles: Combat Outcomes in Iraq and Afghanistan, 2003 - 2013

**Description**  
In order to provide a reference document outlining the combat incidents involving Stryker Vehicles in Iraq and Afghanistan, JTAPIC analyzed all known attacks on Stryker Flat Bottom Hull and Double V Hull vehicles, to include the vehicle outcomes and occupant outcomes in these attacks. In completing this analysis, JTAPIC characterized, in broad terms, the outcomes to Stryker vehicles in these theaters. JTAPIC also provided evidence that outcomes for vehicles and occupants differ depending on the weapon used to target the vehicle. JTAPIC identified that vehicle and occupant outcomes for certain weapons depend on the Stryker variant (FBH or DVH) that is engaged. This data can be used in the future to inform decision makers about combat operations where Stryker FBH and DVH can be used successfully, in order to best protect the vehicle and its occupants.

**Priority**  
Regular

**Expected Product Classification**  
Unclassified

**RFI Type**  
Analysis Request

**Submitted Date**  
2019-Jan-18

**Needed Completion Date**  
2019-Mar-20

**Cross Functional Team Supported**  
Next Generation Combat Vehicle (NGCV)

**Estimated Cost Benefit**  
\$1,000,001+

**Potential Impact**  
This could save soldiers' lives.

**Scope**

Figure 3: Screenshot of Completed RFI From JINCS (Source: JINCS).

medical, and materiel data. JINCS will provide a user interface based on user roles and permissions so users can quickly query the database to perform analysis and view the data in multiple ways to help them better understand it. Analytical tools for data interpretation will be built into the interface to protect data and create efficiencies for system users. The database will strictly be housed on the SIPR network.

## CONCLUSIONS

The JTAPIC Program has created over 400 analysis products for over 40 different DoD organizations and is currently conducting additional requests for information. Combatant commanders, vehicle program managers, materiel/combat developers, medical researchers, life cycle managers, and senior leaders throughout the DoD have requested analysis from JTAPIC. These products provide the most accurate representation of a given problem set, during a particular time, for a specific operational environment to aid in

complex decision support for the DoD. The new online system facilitates JTAPIC and their partnership in their mission to prevent injuries through actionable analysis that gives decision makers the concrete findings they need. The new online system will drive technology and safety for years to come! ■

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**AMY E. W. BEDNAR** is a research mathematician in the Computational Analysis Branch, Computational Science and Engineering Division, Information Technology Laboratory (ERDC). She is currently the program manager developing a new online system for JTAPIC. Most recently, she was the project manager for the research program PLANS (Planning Logistics Analysis Network System), which is a logistical route-planning tool that generates low- to high-range fidelity predictions across different transportation modes (land, air, and sea) and environmental effects. Dr. Bednar holds a Ph.D. in mathematics.

**LINDSAY LIBERTO** is a program analyst with JTAPIC. Caring for severely wounded combat veterans and their families at Walter Reed National Military Medical Center inspired her commitment to injury prevention. She is a certified injury coding specialist. Ms. Liberto holds an M.S. in clinical nursing and an undergraduate degree in kinesiology/biomechanics.

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### SUMMER 2020 DEADLINES

**Abstract:** 2 March 2020

**Article:** 17 April 2020

### FALL 2020 DEADLINES

**Abstract:** 2 June 2020

**Article:** 17 July 2020



(Photo Source: U.S. Army and 123rf.com)

# AUGMENTED TARGET RECOGNITION DISPLAY RECOMMENDATIONS

*By Gabriella Brick Larkin, Michael Geuss, Alfred Yu, Joe Rexwinkle, Chloe Callahan-Flintoft, Jonathan Z. Bakdash, Jennifer Swoboda, Gregory Lieberman, Chou P. Hung, Shannon Moore, and Brent Lance*

## SUMMARY

**I**n light of the U.S. Army's intent to leverage advances in artificial intelligence (AI) for augmenting

dismounted Soldier lethality through developing in-scope and heads-up display-based augmented target recognition (ATR) systems, the Combat Capabilities Development Command (CCDC) - U.S. Army Research Laboratory's (ARL's) Human Research and Engineering Directorate (HRED) identified several critical gaps that must be addressed in order to effectively team the Soldier with ATR for the desired augmented lethality. One of these areas

pertains to the way in which ATR is displayed and requires a thorough understanding and leveraging of relevant cognitive processes that will enable this technology. Additionally, insufficient consideration of perceptual, attentional, and cognitive capabilities increases the risk of burdening the Soldier with excessive, unnecessary, or distracting representations of information, which may impede lethality rather than augment it. HRED's planned

Insufficient consideration of perceptual, attentional, and cognitive capabilities increases the risk of burdening the Soldier with excessive, unnecessary, or distracting representations of information.

and ongoing research is intended to develop novel mechanisms through which Soldiers teamed with ATR will perform more adaptively and effectively than either the Soldier or intelligent system could accomplish individually. Based on HRED's significant expertise in the cognitive sciences and coupled with familiarity with the military-relevant domain spaces, we make the following initial recommendations for ATR information display requirements:

1. ATR highlighting should leverage a nonbinary display schema to continuously encode threat information (e.g., target class/identity, uncertainty, and prioritization).
2. ATR highlighting should be integrated with the target itself instead of functioning as a discrete feature of the display (i.e., highlight the target rather than highlighting a region with the target inside).
3. Information about threat certainty or classification confidence (which can also include priority) should be embedded into ATR highlighting.
4. Yellow highlights may offer advantages for display.
5. Changing information (e.g., target certainty) should be accomplished through formation or modification of highlight gradients rather than sudden changes in the display.
6. Human performance evaluations of ATR should consider incorporating changing threat states and contexts into scenarios for more ecologically relevant findings.
7. Human performance evaluations of ATR should consider incorporating uncued (nonhighlighted) targets and miscued targets (false identifications; e.g., ATR identifies nonthreat as threat) for more relevant findings.

## INITIAL CONSIDERATIONS FOR TARGET ACQUISITION SYSTEMS' ATR DISPLAY

The Army plans to leverage advances in AI through implementation into future dismounted Warfighter systems to augment situational awareness and target acquisition capabilities. The unique constraints of dismounted operations necessitates a cognitive-centric approach in which human capabilities are effectively teamed with intelligent systems. This will provide a total systems performance capability that exceeds what the Soldier or the system can accomplish individually. Successfully teaming the human and AI in this manner will enable the Soldier to allocate his/her limited cognitive resources more effectively, decreasing time and increasing accuracy of target identification and engagement decisions while simultaneously enabling greater situational awareness through the target acquisition system.

Design principles developed to support and accelerate, not replace, Soldier decision making are central to the success of ATR and other intelligent systems. Given the constraints of

technology, coupled with the dynamics of the battlefield (or any complex, real-world context), it is important to consider ATR implementations that convey real-time information about the status of threats in the environment. Further, because intelligent ATR systems will not perform perfectly (e.g., classification of threat statuses across subtly different target categories or due to obscured sensors, limited training data sets, etc.), efficient target detection and engagement decision making will also depend on conveying information for real-time fluctuations in classification certainty in a manner that is intuitive and reliable.

In addition to algorithm uncertainty, it is conceivable that the probable threat status of an actor on the battlefield, particularly as determined by ATR, will also fluctuate. For example, someone with a weapon may conceal it, and someone else may pull out a weapon that was previously undetected. Conventional considerations associated with ATR often do not consider fluctuations in target state or system uncertainty, focusing instead on a binary system in which targets are statically highlighted as either threats or nonthreats. When consideration is paid to fluctuations in probability of a given target being a threat, the fluctuation is thought of from the context of algorithm confidence in its classification and not from the context real-world dynamics that may render actual target threat state uncertain (e.g., a target with a weapon that is not consistently in view).

## AREAS OF CONCERN

Such conceptualizations, if implemented in the real-world battlefield, may result in target highlights that frequently change from one threat category to another (e.g., green to red or highlighted to unhighlighted). There are several potential areas of concern associated

with this that include the following:

1. Inefficiency of the ATR display to convey intuitive information: rapidly changing between threat categories negates the recognition component of the ATR and reduces it to automatic target detection (ATD).
2. Inefficiency of the ATR display to convey usable information: high-certainty nonthreat targets may appear more salient than low-certainty threat targets.
3. Inefficient or detrimental allocation of attentional resources:
  - a. Rapid changes in the display can create a high-salience cue to attention that is distracting, resulting in unintended attention capture. For example, switching between colors or other means to convey categorical distinctions may effectively display as a flicker or result in tunnel vision to specific regions of an image or environment at the cost of dispersed attention where other targets may be present.
  - b. Targets initially displayed as nonthreats may trigger inhibition of attention to the target location, thus failing to capture attention upon target state change or even the appearance of a threat target near that location.
  - c. Distributed attentional resources across all highlighted targets (e.g., such as ATD) will reduce processing allocated to true threats [1].
  - d. Crowding visual information may reduce the ability to discriminate between targets and nontargets [2]; information displays must consider perceptual limitations, such as the drop-off in visual acuity outside the fovea.

4. Ineffective engagement decision making: the human may equally distribute attentional resources across similarly appearing targets without understanding that one target may be a high-certainty threat while another may be a low-certainty threat.

## IMPLICATIONS

Significant work is needed to understand the underlying cognitive processes critical to effective target acquisition and engagement decisions and translate that understanding into designing novel ways to most effectively display information at the point of need. It is essential that these methods consider, complement, and leverage these cognitive processes into mechanisms for effective human-AI pairing that go beyond simply adding more information to the dismounted Soldier's already-burdened cognitive load. However, based upon a holistic consideration of battlefield dynamics and system capabilities discussed, certain implications can already be leveraged. These include the following.

### **1. Conveying Uncertainty Information to Aid Engagement Decision Making**

As described in Geuss et al. [3], future ATR systems are unlikely to perfectly categorize targets as threats or nonthreats due to targets being partially occluded, imperfect data to train machine learning algorithms, and lack of ability to understand or integrate contextual constraints on target relevance. Uncertainty in target classification will also arise from the nature of the dynamic battlefield. Enemy targets will adapt within and across engagements by concealing weapons, altering tactics, and employing deception. ATR systems are likely to either falsely cue targets

ATR systems are likely to either falsely cue targets that are not threats (false alarms) or leave threatening targets unnoticed (misses).

that are not threats (false alarms) or leave threatening targets unnoticed (misses). However, quantifying and communicating the associated levels of uncertainty about target classification in an intuitive manner will improve effective decision making and promote greater trust in the ATR system's capability, if properly displayed.

Several papers have demonstrated that communicating uncertainty information can improve decision making [4–6]. However, the way in which uncertainty information (e.g., the specific visual encoding method used) is displayed can determine whether people ignore uncertainty information or effectively integrate it into their engagement decisions. For example, people use common schema to interpret representations of information that, if misused, can result in misinterpretations, slower processing, inappropriate generalizations, and incorrect decisions.

Another example is “the cone of uncertainty” used to represent the potential path of a hurricane; it is often misinterpreted as a measure of the danger posed by the hurricane due to growing size of the hurricane itself rather than decreasing certainty about its future path [5]. Additional research is needed to identify optimal visual encoding techniques for communicating

uncertainty in target classification based on understanding common cognitive heuristics in operational contexts and how encoding methods could adapt to Soldier state and dynamics. However, it is clear that this is absolutely essential to ensure that proper engagement decisions are made.

## **2. Conveying Threat Information Along a Continuum Rather Than as Associated With Two Discrete (Binary) Categories**

The full limitation spectrum of conventional means for displaying computer-aided visual techniques will not be discussed here. However, Kneusel and Mozer [7] provide a compelling case for using “soft highlighting,” described as blurring the boundaries between the target, highlight, and environment, as opposed to “hard highlighting.” Hard highlighting is the more typically conveyed bounding box (or shape) consisting of an augmented reality (AR) object, distinct from its content, and overlaid onto the scene. In their paper, the authors describe soft highlighting as a means to reduce the detrimental effect that ATR and similar systems have on detecting uncued targets (missed by the system). While numerous mechanisms may cause this effect (the subject of future research), this finding is consistent with findings from radiology and related literatures.

These findings have shown that computer-aided design systems, which use traditional hard highlights to assist radiologists to detect the presence of tumors in scans, result in very little net gain for detecting and identifying the presence of tumors [8, 9]. The soft highlighting approach leverages opacity to signify target certainty, allowing identification of uncertain nontargets

that do not cross the threshold for target status required for visualization using a binary approach. Additionally, soft highlighting is less likely to restrict attention exclusively to targets and obscure adjacent portions of an image or environment.

In addition to the benefits of a soft highlighting technique laid out by Kneusel and Mozer [7], soft highlighting advantages are consistent with findings that suggest having to selectively attend to individual features in object representations may come at a cost to active visual working memory maintenance processes [10]. A hard highlight distinct from its content may require the viewer to attend to the highlight itself and the content of the highlight in order to derive all required information. This also applies to the idea of portraying information about uncertainty as a distinct feature (i.e., a percentage displayed with the highlight).

Visual working memory (VWM) has limited capacity. Processing conjunctions about an object complicates the representation of the object, thereby taxing VWM resources and possibly resulting in less effective (e.g., slower and/or less accurate) processing (see Schneegans and Bays [11] for a comprehensive review). This is consistent with Treisman’s [12] Feature Integration Theory, which posits that different dimensions of the same feature can be processed in parallel, in contrast to an equal number of different features (e.g., three shades of the same hue vs. three different hues). As such, presenting information about targets in a way that allows a strong, cohesive object representation minimizes additional processing associated with multiple features that need separate attention and bound to form a percept. This may better support the desired intent of the ATR display.

Additionally, it has been shown that static cuing paradigms indicate a very rapid decay in enhanced processing effects (e.g., Von Grünau et al. [13]). Burra and Kerzel [14] found that attention capture to a salient distractor is inhibited by the predictability of the presented target (i.e., same or similar target in all search trials), which is consistent with the moderation of efficacy of suppression mechanisms resulting from changing (in this case, unchanging) cognitive demands of the task [15]. This may indicate an advantage associated with somewhat nonstatic or predictable/consistent cues, where attention is allocated efficiently to cued targets within the usable field of view.

A cuing mechanism that is too dynamic or unpredictable may have other detrimental effects.

Of course, a cuing mechanism that is too dynamic or unpredictable may have other detrimental effects. The sudden onset of novel stimuli can capture attention and distract viewers from their primary task, particularly in cases of similarity between the distractor and the true target [16]. Distraction of attention from a given location can reduce perceptual sensitivity at that location (where attention should be allocated [17]), as well as result in other perceptual effects (e.g., modifications to motion perception [18]). Finally, misallocations of attention to a distractor are associated with delayed attention allocation to the relevant target [19].

Note that there are also several efforts suggesting such attention capture is largely under cognitive control (e.g., Theeuwes [20]). However, when inappropriate attention capture is reduced, it is often done through mechanisms of inhibiting processing (reactive mechanism) and suppressing response (proactive mechanism) to distractors (see Geng [21]). This is not necessarily an ideal effect to invoke with a system intended to ensure attention can be cued as needed to multiple objects (targets) within the scene. Additionally, the amplitudes of event-related potentials (ERPs) associated with attention (i.e., N2pc) are reduced for target processing in the presence of even a distractor that failed to elicit that ERP itself. This suggests that even when cognitive control prevents capturing attention by distracting stimuli, it does not eliminate the negative impact of the distractor's presence [22].

A soft highlighting technique lends itself very well to conveying a continuum of certainty in a nondistracting manner. A low-saliency, soft highlight can be applied to all targets (e.g., people) detected within the scene, with changes in a relevant dimension (e.g., opacity, intensity, and size) associated with fluctuations in state of threat certainty. This design supports the parallel feature processing described by Feature Integration Theory and may strike the much-needed balance between static and dynamic cuing paradigms to optimize attentional allocation. In such an implementation, all targets may softly “glow” in a uniform hue, thereby, distinguishing them from the rest of the scene for visual access ease. As the probability of threat associated with a given target increases, visual access increases through saliency (e.g., brighter) manipulation. This, in turn, may decrease as threat state or certainty of threat state changes.

The method of displaying ATR may offer several advantages when minimizing the need to attend to individual features of an object and supporting and facilitating efficient, feature-based object binding. Derived by considering underlying visual-cognitive processes, this method may distinguish targets from background clutter and provide usable and intuitive information about relative target importance to the Soldier while minimizing potential negative effects associated with battlefield uncertainty and attentional resources.

Furthermore, continuous increments of saliency can be implemented gradually to optimize the trade-off between attenuating to static/consistent cues and inappropriate attention capture through excessively dynamic cues. This implicitly manipulates representations of target saliency to reduce the likelihood of attentional capture due to sudden changes in saliency (see Figure 1). Unhighlighted targets in a visual search task (A) identified by ATR can be presented using many different strategies. This includes hard binary highlights that appear

less intrusive than typical bounding boxes (B) or soft highlights that convey nonbinary information representations by varying the brightness (C) or size (D) of the highlights. Softer highlighting enables a higher-dimensional degree of information to convey to the human while simultaneously minimizing the distraction and environmental obscuration induced by the highlight itself.

### 3. Color of Highlight

Research is likely needed in order to truly ascertain the appropriate color to highlight targets via ATR. However, logic dictates that some preexisting associations may exist with colors such as red and green. This may also be nonideal because of confusion with reticle or foliage, respectively, and perceptual issues of these hues for color-blind viewers. Tombu et al. [23] and Reiner et al. [24] demonstrated utility of yellow-colored highlights in their ATR simulation experiments that serves as a recommended starting point. However, it should be noted that these experiments were conducted in indoor simulator environments. The

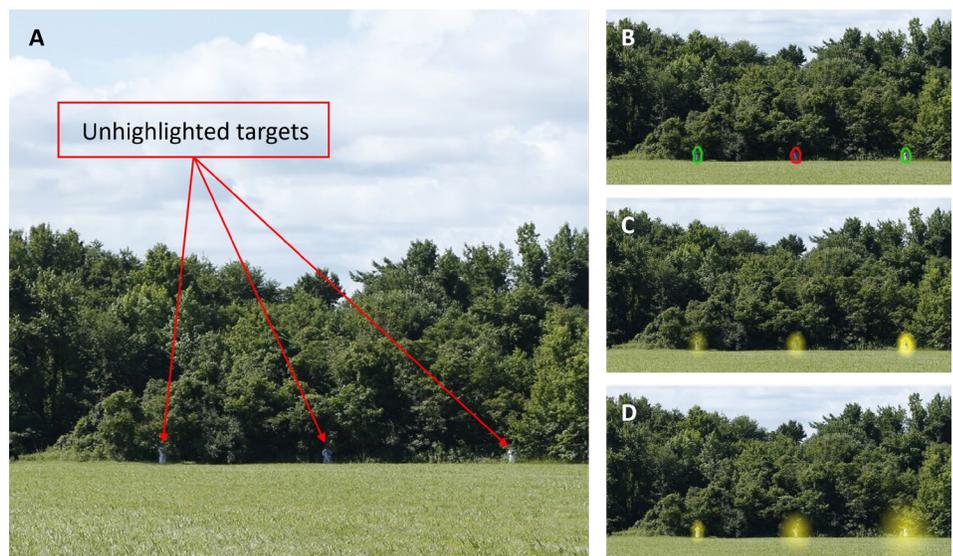


Figure 1: Targets Unhighlighted (A), Highlighted Using Hard Binary Highlight (B), and Soft Highlights of Varying Brightness (C) and Varying Size (D) (Source: ARL HRED).

interaction of this color with natural light and time of day and the type of outdoor environment requires further investigation.

#### **4. Performance Characterization Efforts That Realistically Depict the Fluctuating State of Certainty (System and Human Driven)**

Understanding the true impact of conveying uncertainty to Soldiers through ATR or similar systems must involve evaluating potential display techniques under circumstances likely to interact with technique effectiveness. In the case of fluctuating battlefield certainty, we recommend that scenarios be incorporated into evaluations that include changes in certainty associated with naturalistic human behavior in the real world. This can include object-based obscuration of weapon systems (e.g., threat with weapon walks through brush where weapon is obscured), intentional obscuration of weapon systems (e.g., weapon system is put away or hidden on person), and new manifestations of weapon systems on existing actors (e.g., person takes out a weapon system), with the ATR response adjusted accordingly.

Note that some training will be required to familiarize participants with the construct of continuous threat ATR.

#### **5. General Performance Characterization Considerations**

Critical to truly understanding the impact of ATR and related features on Soldier engagement performance, ATR successes and failures must be considered in performance evaluations. These include, but are not limited to, constructs from traditional signal detection theory—hits (correctly labeled threat targets), correct rejections

Understanding the way in which the ATR display interacts with human visual and cognitive processes is particularly relevant to evaluating Soldier-ATR performance.

(correctly unlabeled nonthreat targets), misses (failure to label threat targets), and false alarms (mislabeling of nonthreat targets). Understanding the way in which the ATR display interacts with human visual and cognitive processes in this context is particularly relevant to evaluating Soldier-ATR performance.

### **CONCLUSIONS**

The literature reviewed here and the recommendations introduce several new research questions that will be addressed over the course of the ARL-HRED Human-AI Interactions for Intelligent Squad Weapons program. However, leveraging our understanding of both the problem space and the relevant literature in support of the scientific development of this program provides a recommendation for depicting target type and uncertainty in a way that considers cognitive implications of ATR display. Further, empirical evaluation scenarios that allow characterizing performance in conditions of real-world certainty state changes will provide a deeper understanding of how uncertainty information can affect target acquisition and engagement decisions. A trade-off is anticipated between optimizing response to target, optimizing

detection of uncued targets, and other critical aspects of performance through the usable field of view. However, an informed conversation about that trade-off is necessary in order to influence Army decisions toward Soldier-centric, optimized target acquisition systems. ■

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# What Does Next-Generation, **PASSIVE RPG** **PROTECTION** Look Like?



By Michael Salvucci, Matthew Magner,  
and Michael Wheaton

*(Photo Source: U.S. Marine Corps)*

## INTRODUCTION

**R**ocket-propelled grenades (RPGs) are a well-known threat to tactical, reconnaissance, engineering, and combat vehicles that operate in hostile environments. Technologies designed to defeat RPG-type threats include active, reactive, and passive armor solutions—each varying in cost, weight, and complexity. Regardless of the system, RPG protection has been a requirement for ground vehicle platforms for over a decade. Many ground vehicle platforms, however, favor passive, fuze-disrupting armors (FDAs) to provide increased RPG protection at the lowest cost and weight burden possible. These FDA systems, also characterized as “statistical armors,” traditionally require bars or slats (steel) for successful system function.

While technically mature, there are limitations in these systems’ compositions. Specifically, direct impact on a hard surface like steel or aluminum may initiate the detonator of the RPG, leading to severe penetration of any substrate in its path, including the vehicle’s armor. Therefore, the ability to limit hard impacts like this provides the best opportunity for realizing potential performance improvements. Optimizing passive RPG protection lies in removing geometric constraints and hard surfaces; this effectively generates a system that is transparent to the fuze.

Foster-Miller, Inc. (doing business as QinetiQ North America [QNA]) and the U.S. Army’s Combat Capabilities Development Command (CCDC) Ground Vehicle Systems Center (GVSC) (formerly the U.S. Army Tank Automotive Research, Development and Engineering Center [TARDEC]) have teamed up to develop a novel passive system constructed from a lightweight, cellular material transparent to the RPG’s fuze. Termed “Advanced

Many ground vehicle platforms favor passive, fuze-disrupting armors to provide increased RPG protection at the lowest cost and weight burden possible.

RPG Defeat Dispersed Media (ARDDM),” this technology eliminates the aforementioned constraints and hard surfaces. Figure 1 shows geometrical limitations in performance (red) and compares ARDDM to slat or bar armor. Based on material composition, note the area in which slat armor is ineffective.

## FIGHTING THE FUZE

Point-initiated, base-detonating fuzes (PIBDs) are commonly used in the detonation chain of threats within the RPG family. PIBDs are equipped

with a piezoelectric crystal designed to generate an electrical charge when facing any nonyielding material. The level of charge generated during an engagement corresponds to the force experienced during impact. The higher the impact force due to the velocity at impact or the mass of the impacted object, the higher the output charge. During these impact events, if the charge is sufficient, a spark will form and trigger the shaped charge of the RPG.

In 2015, QNA hypothesized that if a material could be engineered to have a specific density and stiffness, it would undergo adiabatic shear at the point initiator. It is a complex phenomenon dependent on strain rates but generally thought to occur when thermal softening overtakes strain rate hardening. With the phenomenon that occurs during RPG engagements, this adiabatic shearing drastically reduces the piezoelectric crystal’s ability to generate a charge. ARDDM exploits these principles using a cellular polymeric media, which allows the adiabatic shearing to occur. This engineered material also remains

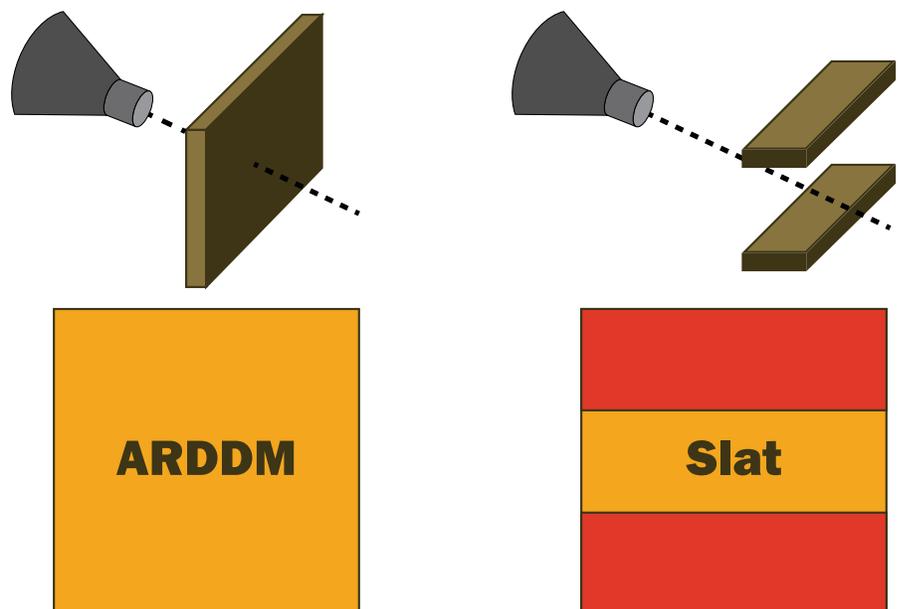


Figure 1: Geometric Limitations (Source: QNA).

suitably rigid to provide a level of durability required to function similar to legacy passive RPG defeat systems. Figure 2 demonstrates the adiabatic shearing effect that occurs during engagement and the fuze disruption through ARDDM's thickness [1].

Early experimental results indicated that material properties needed for fuze transparency and the properties required for passive protection were inversely related. Consequently, changes made to benefit piezoelectric fuze transparency were detrimental to defeat functionality. The material properties that had the most influence on performance were changes to the media's mass and stiffness. However, large reductions in mass from the media negated ARDDM's ability to function as an FDA system.

Traditional passive RPG FDA solutions are independent of piezoelectric fuze interaction and based primarily on shot location and intercept angle. However, ARDDM functions by managing the fuze output, reducing the influence of intercept angle or location. Intuitively, fuzes with higher tested voltage will expend a larger charge during impact, potentially triggering the shaped charge. Hence, fuzes with higher tested voltages are known as "sensitive" fuzes; inversely, fuzes with low tested voltages are labeled "insensitive." Characterization of these fuze types allowed predictive performance of ARDDM. Furthermore, because defeat performance is influenced by fuze sensitivity, this characterization created a high level of confidence going into dynamic (live-fire) testing.

During fuze characterization, all samples responded primarily to changes in velocity (strain rate), mass (density), and stiffness (modulus), with output levels varying based on sensitivity.

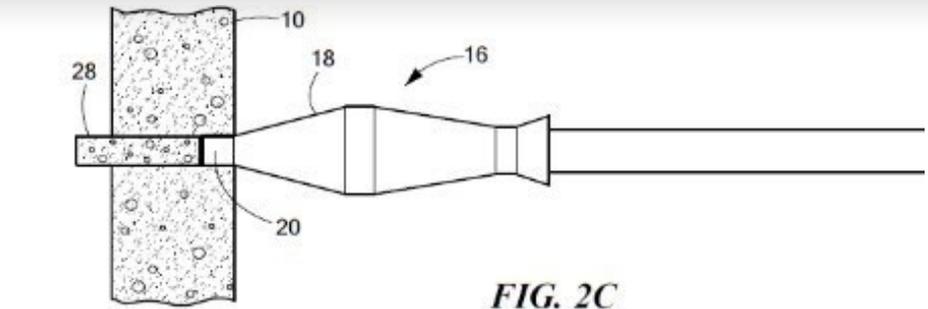


FIG. 2C

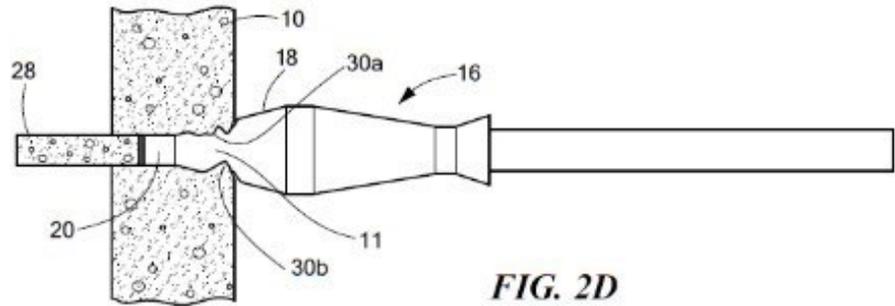


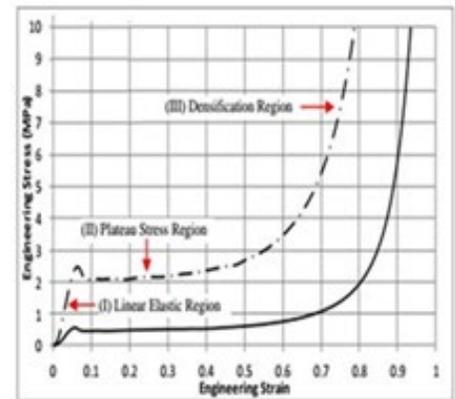
FIG. 2D

Figure 2: Adiabatic Shearing Effect (Sources: QNA and GVSC).

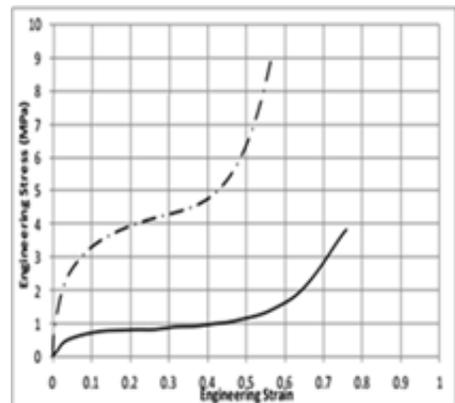
Naturally, variance in impact velocity modified the stress-strain relationship of ARDDM and how well the mechanism would defeat the threat. Additionally, this response is influenced by the material's relative density and relative stiffness ( $\rho^*$  and  $E^*$ ). This stress-strain relationship is a measurement of a specified material's density compared to its solid counterpart. It was determined that medias must be compared in their "relative" forms [2]. Figure 3 illustrates the changes in behavior seen in a stress-strain response, most notably an increase in plateau stress and a shortening to the densification region [2, 3].

### TYPES OF TESTING

ARDDM has been vetted in lab and live-fire environments. Air cannon testing was conducted during multiple stages of development using QNA's rapid test facility (RTF) and GVSC's Air Cannon Lab. The primary function of the RTF was to capture material and threat behavior via high-speed video and analyze its effectiveness as an FDA. Lab devices



(a) Quasi-Static



(b) Dynamic

Figure 3: Stress-Strain Response (Source: Gardner [3]).

were launched at a range of velocities, and experiments were designed to downselect materials based on density, stiffness, and thickness. Figure 4 depicts successive time steps during a test. Note the formation of the “plug” seen exiting the rear of the panel.

Fuze response was measured using two versions of microelectromechanical systems (MEMS) of similar design principle. Both systems (GVSC pictured in Figure 5) were integrated into lab devices for nondestructive testing. These systems were designed to capture data at high sample rates, use variable

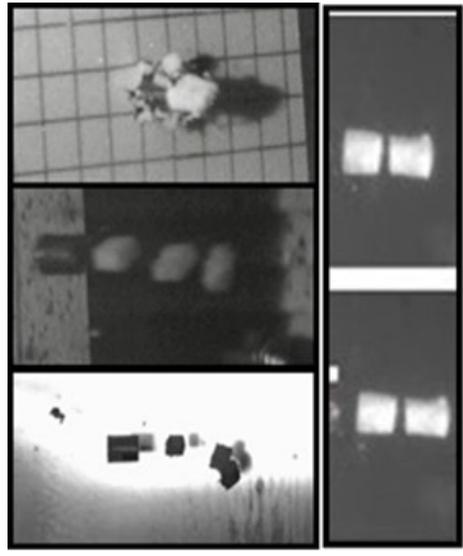


Figure 4: Time Steps During Testing (Source: GVSC).



Figure 5: GVSC Lab Device (Source: GVSC).

triggers mechanisms, and be capable of withstanding extreme G-loading (>300 g). The components in the MEMS were used to trigger data collection, provide power, reduce noise, and ultimately measure the response of the piezoelectric fuze in a lab setting.

Live-fire testing was facilitated by CCDC-GVSC, with on-site support and analysis also conducted via high-speed video capture. Cameras were positioned to capture both the penetration mechanics as well as shot location on the target. By reviewing the high-speed footage between shots, it could be determined what properties required adjustment, how the threat performed, and how ARDDM performed. Multiple engagement scenarios were used in an effort to map ARDDM performance against different conditions.

### CONNECTING THE DOTS

ARDDM’s mechanical properties—mass, density, and stiffness—could only be honed through extensive live-fire and air-cannon testing. The data sets allowed QNA to make a direct correlation between ARDDM’s ability to

be fuze transparent but also maintain fuze disruption. Additionally, increases in mass had a negative effect on fuze output but a positive effect on FDA functionality. The role of engagement, or the velocity of impact at which ARDDM was engaged, changed the mechanical response of the material. This phenomenon reduced the mass required for defeat at velocities while simultaneously increasing fuze response.

Increases in mass had a negative effect on fuze output but a positive effect on FDA functionality.

The mechanical relationship, plotted in Figure 6, illustrates these effects. Three density gradients are plotted as  $\rho_{High} > \rho_{Medium} > \rho_{Low}$ . As shown, when velocity

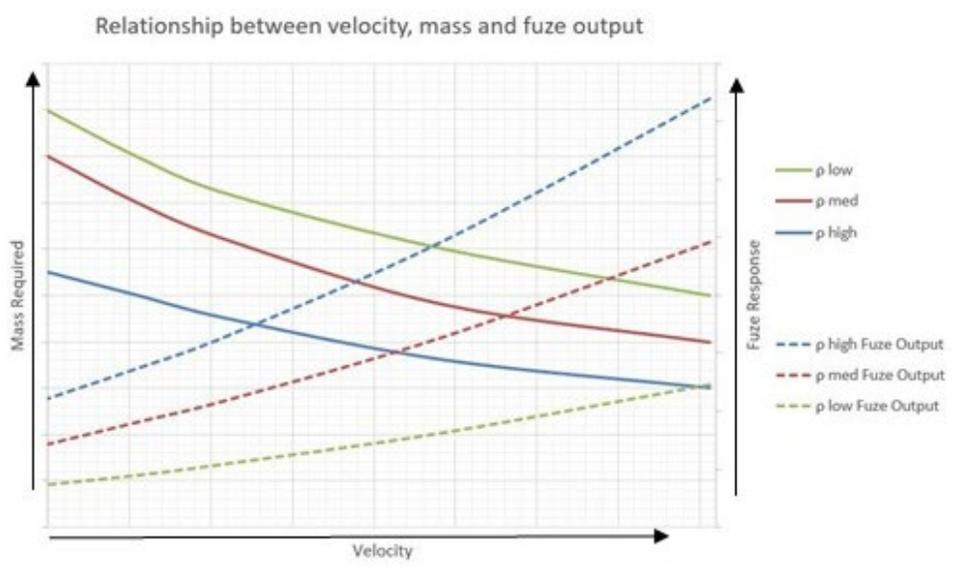


Figure 6: Mechanical Relationships (Source: QNA).

increases (left to right), the required mass or thickness required for fuze disruption is reduced. Alternatively, the corresponding fuze output, represented by a dashed line, increases. This paradigm dictates which fuzes the media could receive, as a fuze of higher “sensitivity” would generate a larger electrical output and potentially trigger a detonation. This also demonstrates ARDDM’s ability to handle increasingly sensitive fuzes at lower velocities.

In order to understand the effects of azimuth and elevation, obliquity testing was conducted. Test results aligned with those that could be extrapolated empirically. Increasing the angle of intercept produced an increase in through-thickness material being penetrated. This effectively increased the shear forces required to “plug” the media and led to an increase in fuze response and lower mass threshold. Additionally, due to the homogeneity of ARDDM, the mechanical response is predicted to behave uniformly, making the changes in elevation response equal to changes in azimuth.

## ENHANCING SURVIVABILITY

Engineered first and foremost to function as an FDA solution, ARDDM provided additional survivability tools that became evident upon testing. Due to ARDDM’s construction, which consists of millions of microscopic, closed-cell air pockets, it is a natural insulator. This secondary property provides a thermal barrier between any two sources (i.e., a vehicle and an observer). Two testing methods were conducted to evaluate ARDDM’s thermal transmission. Figure 7 depicts both methods—the first simulating the MIL-810 vehicle exposure and the second emulating a more extreme but practical scenario. Results are shown in Table 1.

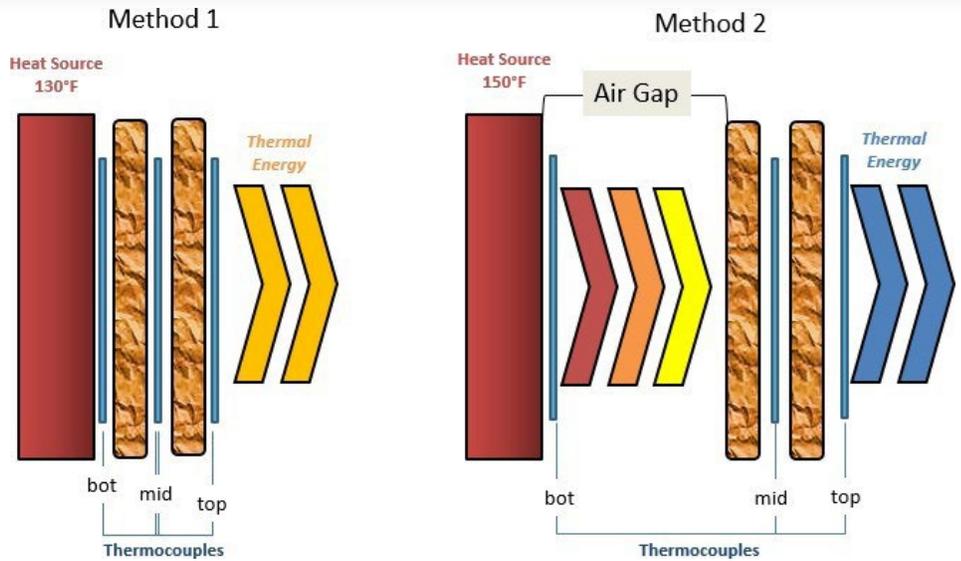


Figure 7: Thermal Transmission Test Methods (Source: QNA).

Table 1: Results From Thermal Testing (Source: QNA)

Method	Exposure Length (hr)	Avg. Temp. (Bottom)	Avg. Temp. (Middle)	Avg. Temp. (Top)	Δ T
1	5	130 °F	102 °F	85 °F	-45 °F
2	9	149 °F	116 °F	93 °F	-57 °F

In addition to thermal mitigation, the air pockets comprising ARDDM collapse when impacted, effectively absorbing large amounts of energy. Following live-fire testing, consistent evaluation of ARDDM samples revealed that large amounts of debris were embedded in the media, capturing a portion of the fragment generated during low-order deflagration and blast. Similar to the fuze and defeat mechanisms, this fragmentation capture and blast mitigation was studied analytically and found to be driven by strain rate.

Figure 8 shows the comparison of lethality in blast pressure from an RPG threat, with and without ARDDM. ARDDM’s energy absorption is strain-rate dependent and exponential, which can be seen by the growing distance in milliseconds between the RPG

overpressure curve and an RPG with an ARDDM mitigation curve. This is due to the difference in shock front velocity between a 1% survival scenario and 50% survival scenario. As the velocity decreases, the material has more time to react and compress, increasing its energy absorption potential. Table 2 shows the reduction in lethality of the blast wave as a function of standoff.

ARDDM’s energy absorption is strain-rate dependent and exponential.

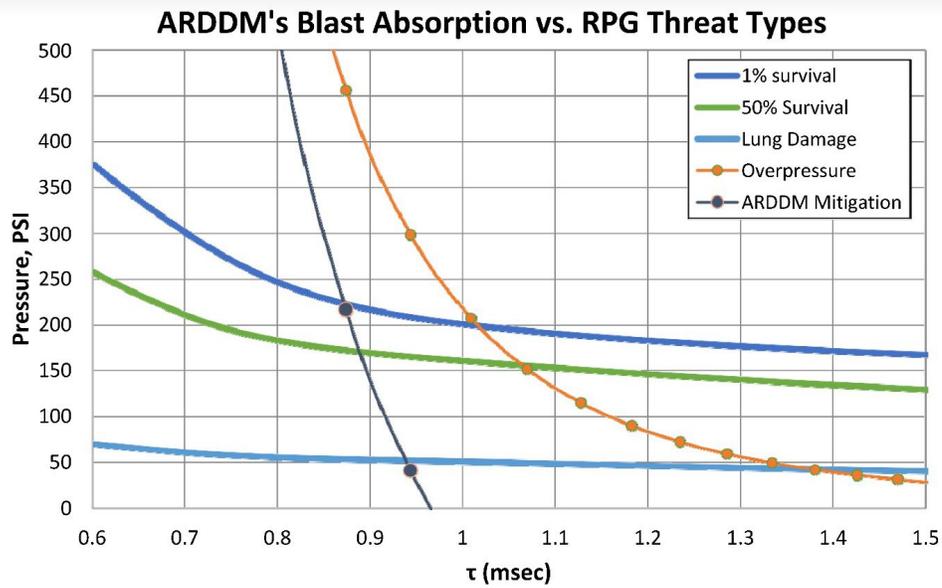


Figure 8: Blast Absorption Curves (Source: QNA).

Table 2: Lethality as a Function of Standoff (Source: QNA)

	RPG			ARDDM		
	$\tau$ (ms)	Distance (ft)	Lethality Decrease (%)	$\tau$ (ms)	Distance (ft)	Lethality Decrease (%)
<b>1%</b>	1.010	2.625	N/A	0.873	1.969	25.0
<b>50%</b>	1.069	2.953	N/A	0.894	2.067	30.0
<b>Lung</b>	1.380	4.921	N/A	0.943	2.297	53.3

In order to quantify the embedded debris found in the samples, a model was generated following Gurney and Mott to determine any reductions in lethality [1, 4–6]. Figure 9 represents a fragmentation scenario aimed to mimic an RPG fragmentation round where the lethal radius equates to 23 ft with body armor and 492 ft without body armor. Twenty-three feet from detonation, the velocity of the fragments generated during an RPG threat of this type can reach 1800 m/s. Assuming mild steel as the fragment material (0.25 in x 0.25 in x 0.25 in), ARDDM can reduce the lethality from 23 ft to 13 ft (43% reduction) when body armor is worn. When no additional body armor is present, this reduction in lethality goes from 492 ft to 239 ft (51% reduction).

### CONCLUSIONS

The development of ARDDM has demonstrated that a passive FDA system can be constructed from a single, cellular, lightweight material. The engineered material removes slats and hard points previous systems relied upon for effectiveness. Testing concluded that ARDDM’s performance is maximized when fuze response is minimized, whether by the studied adiabatic shearing or by tailoring mechanical properties. The correlation between material properties, impact velocities, and fuze response was also studied, indicating an inverse relationship between fuze response and mass required for defeat functionality.

Additionally, the thermal properties of ARDDM were investigated in order to determine its impact on a vehicle’s signature. Testing demonstrated a significant temperature gradient (>35%) in the through-thickness direction of the material. ARDDM’s reduced thermal signature (85 °F) would dramatically reduce the contrast between ambient conditions (68 °F) and operating vehicle temperatures (130 °F).

Lastly, evidence of ARDDM as a means for high-velocity fragmentation capture was observed, and a theoretical analysis confirmed its potential. These findings reveal a technology which contains the added benefits of decreasing soldier lethality.

Postanalysis results of ARDDM demonstrate a highly capable FDA system at ranges where other systems are more inept. For those reasons, ARDDM would be well suited as a complement solution to active protection systems (APS). The combination of its fragmentation lethality mitigation and ability to reduce blast pressures generated during APS near intercept events makes ARDDM a welcome addition to the U.S. military arsenal of state-of-the-art protection systems (Figure 10).

Due to the cost and weight burdens of current active systems, passive protection will continue to be essential. Effective RPG protection will be critical in safeguarding the Warfighter from the ubiquity with which RPGs are stockpiled. ARDDM provides multifaceted survivability by combining lightweight RPG protection with innate signature management and fratricidal mitigation. ARDDM’s capability serves as a holistic solution that compliments today’s APS while providing the adaptability necessary for future combat vehicles. ■

## ARDDM Improved Fragmentation Protection

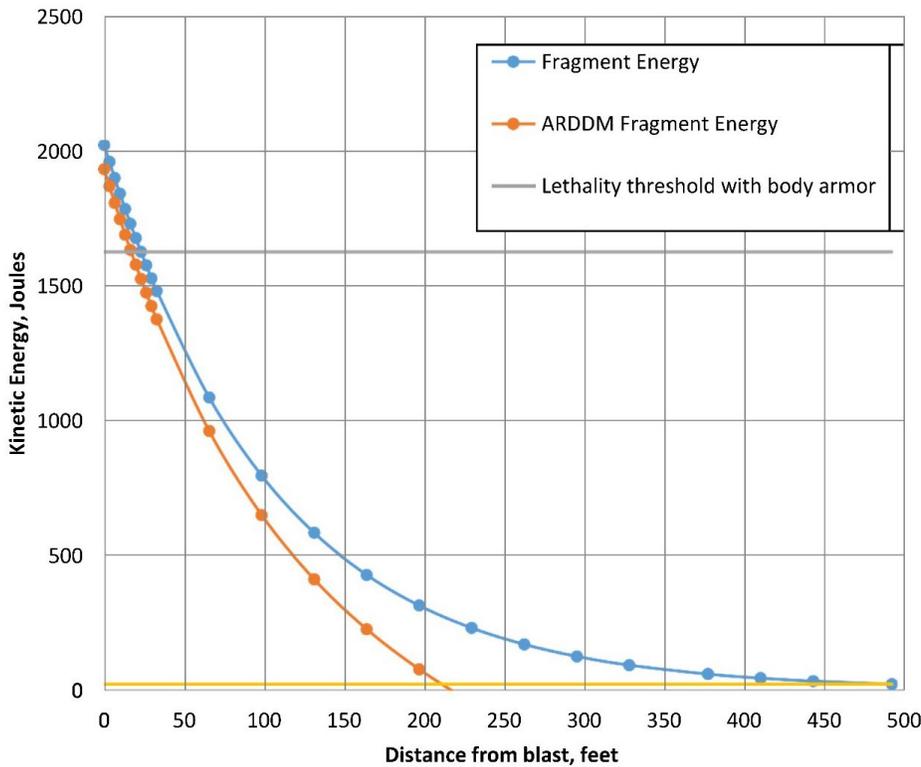


Figure 9: Fragmentation Protection (Source: QNA).



Figure 10: Prototype ARDDM Kit Integrated Onto M113 Troop Carrier (Source: QNA).

Effective RPG protection will be critical in safeguarding the Warfighter from the ubiquity with which RPGs are stockpiled.

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## BIOGRAPHIES

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