Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) Program

In FY24, the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) program applied modern software development methods to demonstrate the ability to increase the capability, user interface, experience, and integration of weaponeering tools more effectively and efficiently.

JTCG/ME uses target vulnerability data, standards, methodologies, and processes to advance the weaponeering capabilities and accuracy of lethality effects and collateral damage estimation (CDE) against kinetic, maritime, cyber, electromagnetic spectrum (EMS), and directed energy targets. In FY24, the JTCG/ME program used automated data collection to collect over 250,000+ strike and 48,000+ mission report products to analyze, inform reach-back support, and support weaponeering tool verification and validation, training, and expenditure analysis. In FY24, JTCG/ME generated 15 reach-back packages for weaponeering, CDE, and munition effectiveness assessment in support of current operations.

In coordination with the Joint Live Fire (JLF) program, JTCG/ME also continued to collect data to underpin the methodology required to advance full-spectrum survivability and lethality methods and tools applicable to operations planners and OT&E and LFT&E of DoD systems and services.

PROGRAM OVERVIEW

The JTCG/ME program was chartered in 1968 to serve as the DoD's focal point for munitions effectiveness information. It started by delivering Joint Munitions Effectiveness Manuals (JMEMs) – the sole source for all non-nuclear weapons effectiveness data and methodology for the DoD. The JMEMs have been the "how to" manuals for determining the type and number of ordnances on target. Today, JMEMs have transitioned to kinetic and non-kinetic tools used in operational weaponeering, and CDE in direct support of multi-domain operations, mission planning, and training. These tools are used by joint and Service planners in force-on-force effect estimations, mission area analysis, requirements studies, and weapon procurement planning. These tools are also used by the Service acquisition community in performance assessments, analyses of alternatives, and survivability enhancement studies. These include:

- The Digital Imagery Exploitation Engine (DIEE), a tool that enables users to plan and execute kinetic strikes by seamlessly performing the following Advanced Target Development steps:
  1. Geographically locate and characterize the target
  2. Weaponeer the target using JMEM Weaponeering System (JWS)
  3. Perform target coordinate mensuration
  4. Determine CDE using the Digital Precision Strike Suite Collateral Damage Estimation (DCiDE) tool
  5. Produce and output graphics to the appropriate databases
- The Joint Anti-Air Combat Effectiveness, a tool that supports development of aircraft and weapon tactics using the Joint Anti-Air Model (JAAM). Operators across the DoD are using JAAM daily to refine planning and debriefing air combat tactics, techniques, and procedures (TTP).
- Weaponeering tools capable of estimating lethal effects for directed energy weapons (DEW), cyber, maritime targets, and EMS fires.

The JTCG/ME program executes the JLF program. JLF performs a critical role within the survivability/lethality analytic community by delivering infrastructure, models, simulations, and data to support testing and experimentation of kinetic and non-kinetic systems in operationally relevant contexts to inform, improve, and act as a consistent foundation for LFT&E and warfighter tools and techniques.

MISSION

The JTCG/ME program develops, advances, and sustains weaponeering tools. These tools, frequently referred to as JMEM products, are used by the combatant commands (CCMDs) to estimate and optimize the type and number of U.S. offensive kinetic and non-kinetic capabilities required to achieve the desired lethal effect. These products support assessment against a range of kinetic and non-kinetic strategic or tactical targets, while mitigating risk for collateral damage including civilian casualties.

JTCG/ME partners with the JLF program to develop and enhance full-spectrum survivability and lethality digital tools (including kinetic and non-kinetic effects); improve survivability and lethality T&E methods and processes; and enable live data collection to support rigorous verification, validation, and accreditation of survivability and lethality digital tools.

FY24 KEY ACTIVITIES

» DELIVERING CREDIBLE WEAPONEERING TOOLS TO CCMD STRIKE AUTHORITIES

JMEMs are used daily by warfighters worldwide in direct support of operations, mission planning, and training. The user base includes approximately 26,000+ accounts, spanning the following entities:

- DoD Service members
- Joint Staff/CCMDs
- Multiple coalition partners
- Acquisition community

- T&E enterprise
- Intelligence Community
- National Laboratories

In FY24, JTCG/ME fielded updates to DIEE to improve product accuracy and efficiency in support of operational warfighters. Specifically:

- In collaboration with Office of the Under Secretary of Defense for Intelligence and Security (OUSD(I&S)) and the Joint Staff Directorate for Intelligence (J-2), JTCG/ME has been improving the efficiency and effectiveness of the Joint Targeting Intelligence process by developing, standardizing, and integrating the Advanced Target Development federated workflow management tool, Workflow Application for Recording Products and Targeting History (WARPATH). As part of this process, operational users will be able to link desired effects to tactical tasks outlined in operational plans, which will increase the probability of meeting the commander's objective via enhanced integration and connectivity across the targeting enterprise to enable targeting at scale.
- JTCG/ME has been applying modern software development methods to enable continuous and incremental improvement in capability, user interface, and experience of JWS tools. JTCG/ME also added new weapon and weapon trajectory data to its scene-based weaponeering products, allowing the strike authorities to account for enhanced technologies and capabilities in their calculations of target defeat. To maintain consistency with the latest National Geospatial-Intelligence Agency mensuration methods, JTCG/ME updated calculation tools for both Mensuration Services Program and Common Geopositioning Services.
- JTCG/ME completed updates to collateral effects radii tables, reducing their error margins. It advanced the friendly force collateral effects library mitigation tool to increase the efficiency of collateral effects analysis and enhance risk estimate distance calculations used by DCiDE.
- The JLF program responded to DOT&E requests for information related to Traumatic Brain Injury (TBI). The program also hosted a large technical exchange to evaluate the current understanding of TBI from blast events and identify paths forward for improving characterization, prediction, and mitigation of TBI. JLF is partnering with Defense Center for Public Health, U.S. Army Medical Research & Development Command, and DOT&E to bring together the acquisition, analytical, operational and medical communities to execute projects designed to better inform the risk of TBI from blast events associated with weapons employment and training.
- JTCG/ME generated 15 reach-back packages for weaponeering, CDE, and munition effectiveness assessment in support of current operations.
- JTCG/ME facilitated 23 training classes/events for 350+ students. Training of integrated product capabilities (DIEE/JWS) continues to enable the operational community to successfully employ munitions while minimizing collateral damage.

» ADVANCING THE CAPABILITY, EFFICIENCY, AND ACCURACY OF TARGET DEVELOPMENT TOOLS

JTCG/ME advances the efficiency and accuracy of target development tools for a complex and dynamic multi-domain environment. JTCG/ME upgraded existing weaponeering capabilities to increase the effectiveness of kinetic strikes and developed new capabilities to enable deliberate and dynamic engagements using cyber, EMS, and DEW capabilities.

Advanced Target Development

The DIEE is a vital software program for the targeting enterprise at the global level. The DIEE provides digital solutions to the essential Joint Targeting Cycle functions for both the U.S. and coalition partners.

The DIEE software turns current workflow inefficiencies into automated and integrated solutions within one ecosystem. DIEE's essential targeting functions apply across the targeting spectrum and address basic, intermediate, and advanced target development. Key functions include target coordinate mensuration, weaponeering methodologies using

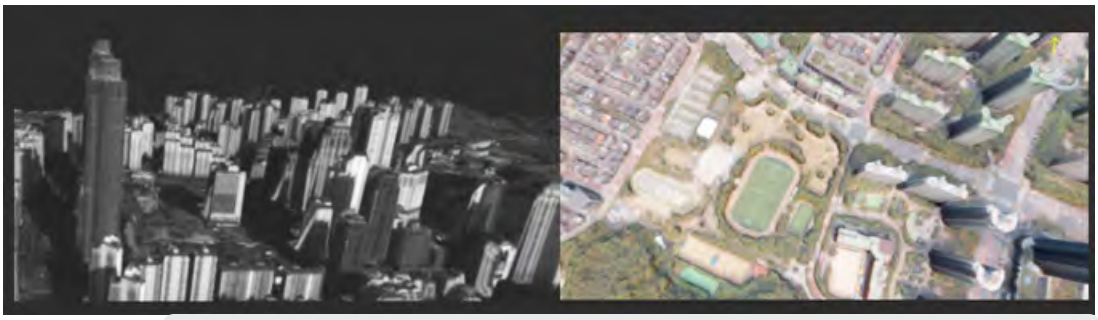

Figure 1. Examples of native 3D viewing capability no longer requiring additional hardware

JWS, CDE effects using the DCiDE tool, targeting graphics production, and combat assessment.

FY24 accomplishments include the first release part of the 3.x product baseline - DIEE v3.0.1. This release includes new capabilities such as native 3D viewing without hardware dependencies (as shown in Figure 1), ability to perform mensuration on emerging 3D datasets, and initial support for the Capability Solutions Package (CSP) construct. This version also includes updates to DCiDE to remain compliant with the latest policy updates. In addition, integration efforts with JWS and other external services/tools continues in support of all phases of target development.

As part of the OUSD(I&S) and J-2 Joint Target Intelligence Modernization (JTIM) initiative, JTCG/ME initiated the development of a federated workflow management tool, WARPATH. This tool aids in streamlining the targeting enterprise production, tracking process while reducing duplicative efforts and costs. WARPATH will be a standalone web application that is interoperable with DIEE and all other JTIM associated programs.

Weaponeering

The JWS combines a series of weapon system characteristics, delivery accuracy, and target vulnerability data needed to estimate the final aimpoint, delivery conditions, and number of weapons on target necessary to achieve combatant commanders desired lethal effects. In FY24, JWS v2.4.2 continued sustainment efforts with the next planned release in late 2024 to support urgent operational needs and to align with DoD cybersecurity requirements. The next generation JWS 1.x plug-in product line continues development of weaponeering capabilities including structural targets (shown in Figure 2), interior and exterior personnel, materiel targets, modernization of weaponeering support tools, and integration with DIEE 3.x. Capabilities of future versions of JWS include continued expansion of auxiliary tools, buried structures, bridge and linear targets, and the incorporation of higher fidelity methodologies for improved result computation.

CDE

In FY24, JTCG/ME made significant progress toward improving the ability of the DoD and coalition partners to accurately characterize the CDE associated with lethal effects of U.S. weapons. Specifically, JTCG/ME continued the execution of the multiyear Enhanced Weaponeering and CDE test program to quantify the collateral effects resulting from munitions detonating either in the ground or beneath structures. Data sets from the Enhanced Weaponeering and CDE test

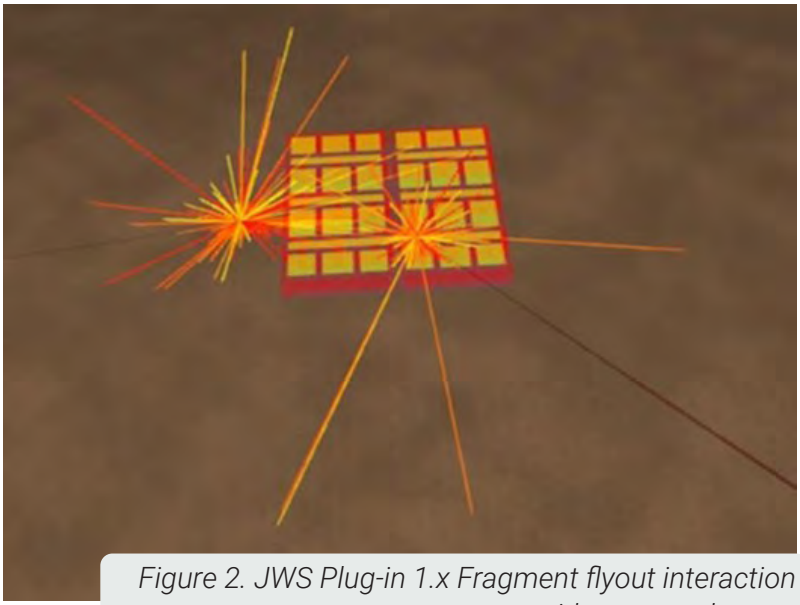

Figure 2. JWS Plug-in 1.x Fragment flyout interaction with structural target

Figure 3. Buried ordnance test conducted in partnership with the U.S. Army Engineer Research and Development Center at Fort Johnson, Louisiana

program were used to improve, verify, and validate high fidelity digital tools used to predict building debris mass and velocity distributions from multiple structure types, along with crater ejecta, ground shock, and blast pressure for various soil types and munition burial configurations. The uncertainty in these predictions must be minimized, as they are the foundation for fast-running engineering models used by the DCiDE tool and JWS to estimate weapon collateral damage and lethality.

In FY24, JTCG/ME conducted multiple tests to further the understanding of munition burial (as shown in Figure 3) and building debris effects on personnel and nearby structures (as shown in Figure 4). These live data supported the evaluation of below-ground detonations beneath a covered surface and two-story structure, along with the mitigation of blast and fragmentation effects and the hazards from secondary debris enhancing the validation of the weaponeering and CDE tools. This test program has also offered collaboration opportunities for multiple organizations to gather data for other modeling and simulation (M&S) and methodology development efforts.

Battle Damage Assessment (BDA)

JTCG/ME continued the multiyear effort of verify, validate, and advance the effectiveness of JMEM weaponeering tools by capturing perishable strike information for future analysis. The goal of the BDA program is to collect all strike information to not only analyze strikes and inform reach-back support, but also to support weaponeering tool verification and validation, training, and expenditure analysis.

In FY24, JTCG/ME used automated data collection tools to collect over 250,000+ strike and 48,000+ mission report products from U.S. Central Command, U.S. Africa Command, and U.S. European Command. The data was integrated in the cloud based Joint Battle Damage Assessment Repository (JBAR) and data views were created to analyze the collected information through spatial and data queries (as shown in Figure 5).

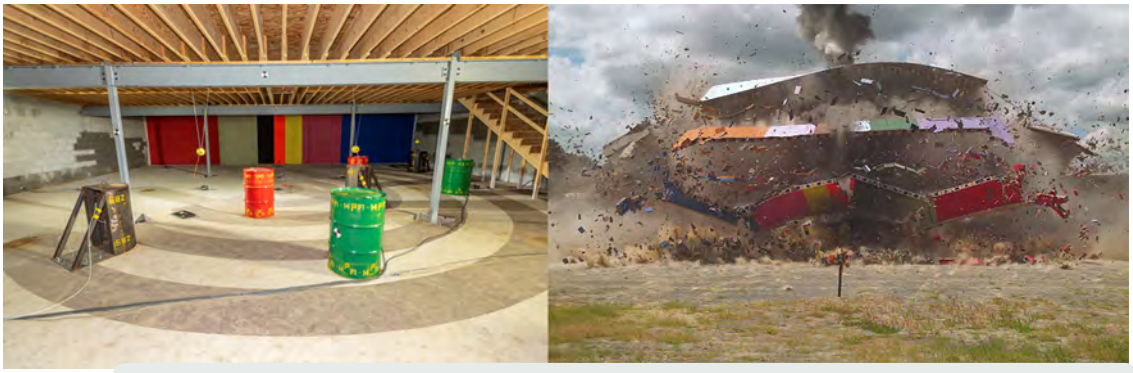

Figure 4. Two-story over-burial building debris test conducted in partnership with the U.S. Army Aberdeen Test Center at Aberdeen Proving Ground, Maryland

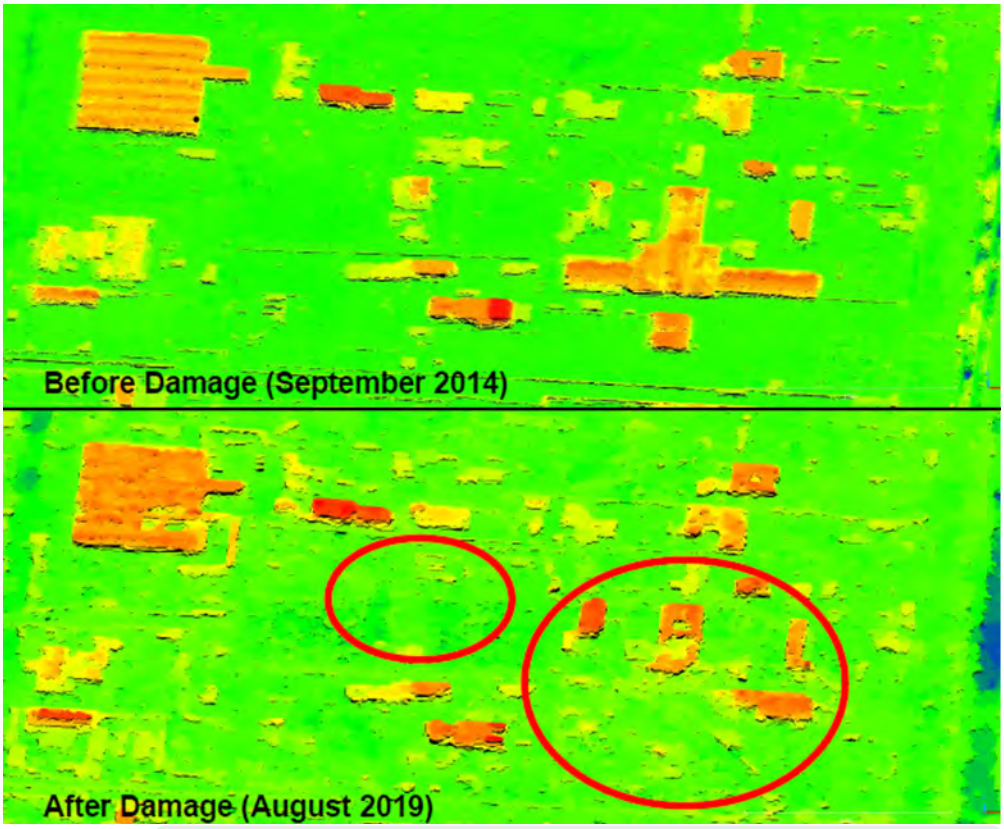

Figure 5. Data collection and analysis of strike event using JBAR

Representational state transfer services are being developed for the hosting of stored data so that strike information can be accessed through an application programming interface (API) with other JTCG/ME.

Lethality/Survivability Improvements

The JLF program continued to improve lethality/survivability assessments and analyses. JLF is uniquely positioned to support DOT&E initiatives and emerging technologies as well as transition the M&S, tools, data, and methods into JTCG/ME operational tools. FY24 JLF efforts included kinetic and non-kinetic lethality improvements. Specifically:

- The Advanced Warhead Characterization, Behind Armor Debris Modernization and Active Protection Systems Enhancements projects improved testing, data collection, and characterization, using advanced analytics and high-fidelity M&S. These improvements were shared throughout the testing, analytic, and operational communities; including the International Test and Evaluation Association, the Test and Resource Management Center, Range Commanders Council, and through international partnerships.
- The Aluminized High Explosives Modeling & Simulation (AHEMS) project dramatically improved the characterization of these unique explosives. Through testing, validated high fidelity M&S, and transitions to fast-running codes, the AHEMS project is bringing accurate predictions of aluminized explosives to warfighter applications, resulting in direct improvements to over 20 existing weapon systems available on current advanced target development tools. AHEMS delivered seventeen technical reports, test data, and improved state-of-the-art high-fidelity codes used by DoD and Department of Energy experts.
- JLF pushed the boundaries of lethality analysis by investing in artificial intelligence (AI)/machine learning (ML). Prototype projects included fitting AI/ML regressions to fragment penetration codes, target vulnerability data, and effectiveness data. AI/ML mathematical fit of effectiveness data have been hosted on a cloud environment to create a first of its kind JTCG/ME Effectiveness as a Service which opens the access to JTCG/ME effectiveness data through computer-to-computer communications via APIs.
- JLF supported DOT&E testing and analysis through improvements to test infrastructure and capabilities. Testing apparatus for multi-shot burst fire were delivered to Aberdeen Test Center. Wireless detonation, which provides reliable and safe detonations for Full Ship Shock Trial, was delivered to Naval Surface Warfare Center. JLF testing and analysis conducted on helmets have shown that obliquity angles of bullets have significant impact on

penetration, and therefore survivability, and will inform future testing requirements.

Lethality of Hypersonic Weapon Systems

In FY24, JTCG/ME and JLF finalized projects addressing the shortfalls related to the evaluation of lethality and associated weaponeering tool capabilities for hypersonic weapons. Hardened autonomous target rafts for Broad Ocean Area testing were delivered to Lawrence Livermore National Laboratories. Autonomous drones with encryption capabilities were delivered and used during recent hypersonic test events. Optical and infrared fragment tracking software has been integrated into the JLF Advanced Warhead Characterization program. Single large mass projectile penetration, cratering, and shock effects were tested, and results have been integrated into high fidelity and fast running codes to improve characterization and effectiveness prediction of hypersonic systems.

Lethal Effect Estimates – Maritime Targets

In FY24, JTCG/ME continues to enhance the ability of weaponeering tools to support the warfighter with credible and timely lethal effects estimates against adversary maritime (surface and subsurface) targets. Within this effort, JTCG/ME has developed the "Maritime Weaponeering Handbook," covering several maritime targets not currently in JTCG/ME inventory. Version 1.0 of the "Target Damage Cards" software, developed by JTCG/ME (shown in Figure 6) will be integrated in the next release of DIEE and enable an interim maritime weaponeering analysis tool for surface and ultimately subsurface targets. JTCG/ME is developing the Maritime Combat Effectiveness (MaCE) operational weaponeering tool, (shown in Figure 7), building on, and adding to, the capabilities of "Target Damage Cards," and integrated into DIEE via plug-in methodology. As indicated in Figure 7 workflow, MaCE will feed CSP data to DIEE.

JTCG/ME continues to execute a collaborative test program that procures data to close knowledge gaps, improve current analytical tools and methods, and

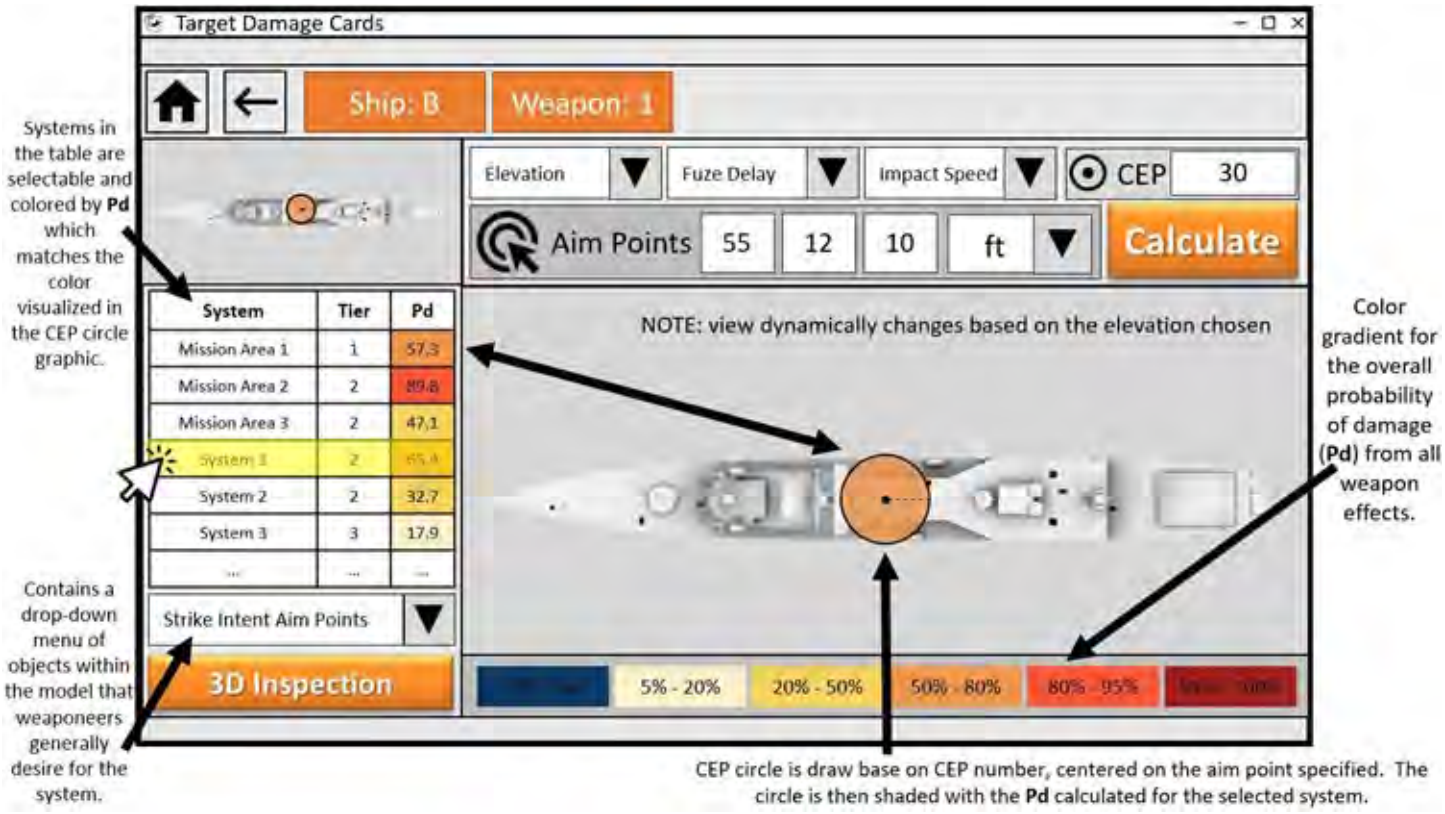

Figure 6. Maritime Target Damage Card visualization tool

develop advanced digital tools required to support the delivery and fielding of weaponeering tools against such targets. This includes the Integrated Naval Simulation for Threat Effects, which will be an engineering level model replacing multiple existing tools and offering best of breed methodologies from those tools for both surface and subsurface targets. Work continues to advance capabilities across the federation of tools, including initiatives related to the Submarine Vulnerable Effects Model, Navy Enhanced Sierra Mechanics, and Dynamic System Mechanics Advanced Simulation. This includes testing and methodology development to predict fire initiation within targets. These efforts increase weapons systems' lethality against foreign maritime threat platforms and will also support more effective and efficient survivability evaluation of U.S. ships and submarines in support of LFT&E objectives.

Aircraft and Weapon Tactics

The JAAM tool is a two-sided operational tool to visualize air-to-air and surface-to-air threat engagements. Prime users of the JAAM application, developed under the Joint Anti-Air Combat Effectiveness Integrated Product Team, are warfighters at test, training, and operational squadrons. Operators are using JAAM daily to support planning, post-mission debriefings with playback, and tactics evaluation with refinement of air combat TTP. JAAM is used across the DoD at 370 sites and 5,600 users. JAAM is used by:

- Operational squadrons
- OT&E ranges
- Mission playback and debriefing applications (government and contractor software)
- Intelligence and acquisition community development of tactics documents
- DoD analysts
- Air, land, sea, space application center fighter interaction team
- Mission planning suites (joint mission planning system - Air Force and Navy)

The JAAM v5.x series is approaching its end of life. The JAAM v5.x series is two-decades old and maintenance is difficult to sustain. The JAAM v6.x series is an entirely new application with a new graphics library and modern architectural design. The JAAM v6.x design includes the following three major components:

- The graphical user interface (GUI)
- The external API
- The Agile Combat Effects Library (ACEL)

The JAAM v6.x GUI (Figure 8) is designed to streamline workflow for the operator. The GUI is designed for three primary use cases: interactive users, virtual range users with event playback to include multiple participants, and iterative studies users supporting few-on-few combat engagements. Specifically:

- Interactive: JAAM v6.x supports one-on-one and few-on-few engagement conditions with detailed aircraft and

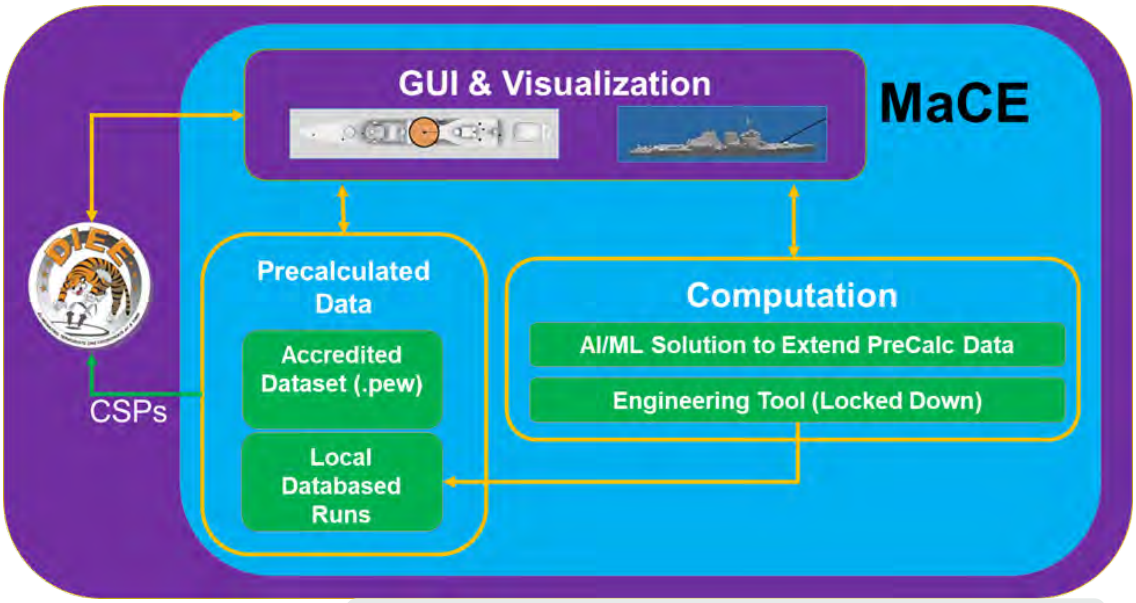

Figure 7. MaCE operational weaponeering tool workflow

weapons metrics and displays. JAAM displays show aircraft and weapon flight paths and key tactical events, such as detection, weapon launch, weapon active, and target killed.

- Virtual Range: JAAM v6.x supports event playback data from Air Ranges (Time-Space-Position Information, aircraft cartridge data, and GPS cartridge data) and injection of weapon shots against targets and evaluation of engagements.
- Iterative Study: JAAM v6.x multi-processors computing to enable multiple aircraft and weapons with hundreds of thousands of parametric engagement conditions. Results are exportable for big data analysis.

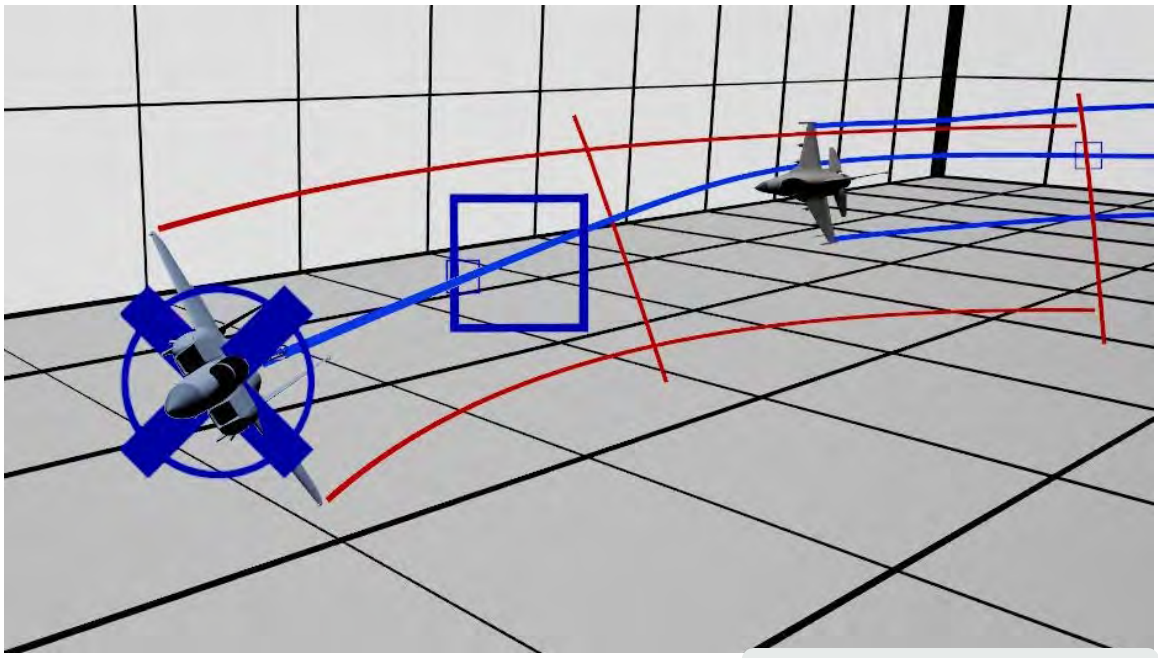

Figure 8. JAAM Interactive GUI

The JAAM v6.x external API is used across the Air Force and Navy Test and Training Ranges which enables authoritative and consistent results within mission playback and debriefing applications. JAAM API is used by:

- Personal Computer Debriefing Systems
- Tactical Combat Training Systems
- Joint Debriefing Subsystems
- Individual Combat Aircrew Display Systems
- Live Mission Operations Capabilities

The numerical engine, ACEL, which includes supplier's simulations and data, are a major component of JAAM v6.x. ACEL is co-developed with the JTCG/ME and the Joint Aircraft Survivability Program (JASP) Office, as discussed in the JASP section of this Annual Report ("SLATE and ACEL Architecture"). The Integrated Product Team manages the collection of simulations and data from multiple suppliers. The suppliers' simulations and data are interfaced into ACEL and ACEL API have evolved to meet JAAM v5.4 capabilities and the initial set of JAAM v6.0 requirements for Medium/High and Low Altitude Multi-Domain two (2)-Sided Air Combat Analysis capabilities (Figure 9). FY24 activities included:

- Signature datasets
- Aircraft and rotary wing datasets
- Weapon lethality and target vulnerability simulations and datasets
- Air-to-Air missile simulations
- Land Surface-to-Air missile simulations
- Early warning and acquisition simulations

JAAM v6.x and ACEL are well suited for addressing the operational needs supporting multi-domain air combat capabilities at an operationally significant pace.

Data Management

To support the implementation of the DoD Data Management Strategy in FY24, JTCG/ME expanded the repositories for archival, review, approval, and access of lethality and vulnerability data,

methodology, and documentation. The four following repositories serve multiple user communities with corresponding features and capabilities:

- For data, the Joint Analysis Repository and Visual Interface System (JARVIS) is a web-accessible repository with the authoritative data to support JTCG/ME's portfolio of warfighter applications. A critical requirement is to facilitate the data development and joint-Service review and approval processes. This repository also serves the T&E and acquisition community by providing JTCG/ME approved target vulnerability packages. In FY24, JTCG/ME deployed several updated versions of JARVIS that provided significant enhancements including data management capabilities for weapon characteristics and pre-generated weaponeering results.
- For methodology standards and practices, JTCG/ME created the Joint Effects Library, as the official repository for all implemented methodology and supporting functions that are approved by JTCG/ME and used in weapon effects applications. Not only does it serve as an archive for all JTCG/ME approved modules, but it also enables the incorporation of standard acceptance workflow and supporting material. The intent is to improve quality, increase reusability and reliability, and reduce time to integrate modules into weaponeering applications. In FY24, JTCG/ME incorporated several additional modules into the Joint Effects Library to support penetration effects, cratering, material targets, and blast effects.
- For documentation, the Bugle is a wiki-style website built on Defense Technical Information Center's DoDTechipedia platform. Hosting on DoDTechipedia makes JTCG/ME's technical reports, data requests, and model documentation accessible to the DoD community. In FY24, additional content was added to share information and collaborate on JTCG/ME products, models, and methodologies. In addition, JTCG/ME improved the site navigation and the overall user experience.
- JLF created a Service Specific Repository which serves as a target vulnerability database for the acquisition community. Analysts can use the repository to store, manage, and share target vulnerability data throughout the acquisition

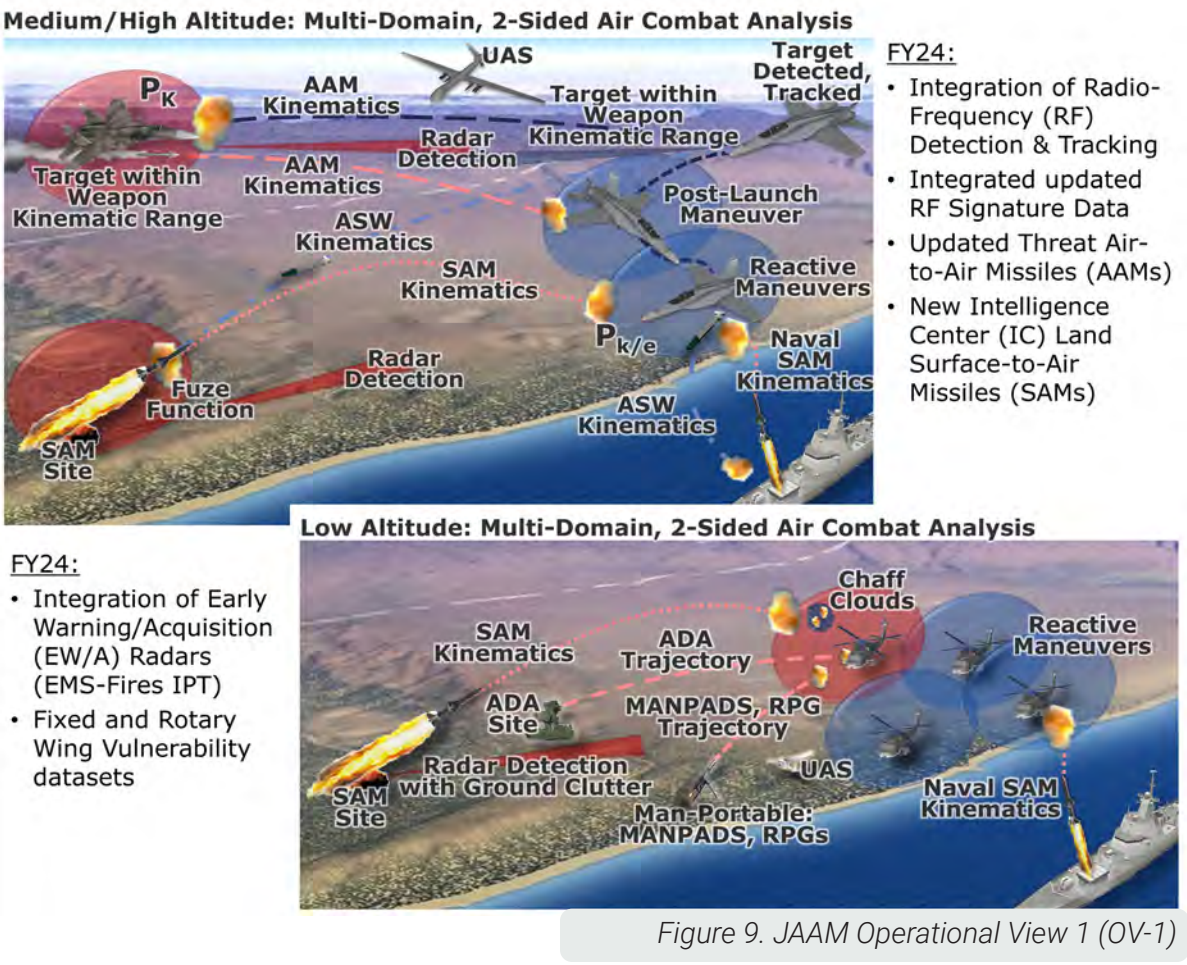

Figure 9. JAAM Operational View 1 (OV-1)

community. This service also has the capability to send target vulnerability data directly to JTCG/ME for use on warfighter tools. The product was deployed in September 2024 and is being used by Army, Navy, and Air Force analytic agencies.

These four repositories work in conjunction to provide joint-Service approved munition effectiveness data, methodology, and documentation within JTCG/ME, JLF, and throughout the DoD.

» ENABLING MULTI-DOMAIN SUPERIORITY WITH DEW, CYBER, INFLUENCE OPERATIONS, AND EMS FIRE WEAPONEERING TOOLS

In FY24, JTCG/ME has made significant progress in multi-domain analysis capabilities and worked in partnership with the Services, Department of Energy's National Laboratories (e.g., Sandia, Lawrence Livermore, Idaho), academia (e.g., Georgia Tech, Johns Hopkins Applied Physics Laboratory), and DOT&E field activities (e.g., Center for Countermeasures, JASP, T&E Threat Resource Activity). JTCG/ME continued support to the warfighter with weaponeering tools intended to integrate kinetic and non-kinetic fires for optimized mission and lethal effects, while mitigating collateral effects to noncombatants, infrastructure, facilities, and equipment. While JTCG/ME has focused on the development and fielding of separate weaponeering tools that can account for DEW, cyber-attacks, and EMS fires, it has also initiated the plans to provide an architecture for a single JWS capable of estimating the appropriate number and type of either kinetic or non-kinetic weapons, and their combined effects, required to achieve superiority in a multi-domain operational environment.

DEW

In FY24, JTCG/ME continued to develop and validate DEW weaponeering tools – Joint Laser Weaponeering Software (JLaWS) and Joint High-Power Microwave (HPM) Applied Weaponeering Knowledge Software (JHAWKS)– to enable the CCMDs to estimate lethal effects using high energy lasers (HEL) and HPMs.

JLaWS

JLaWS uses target vulnerability data, weather effects, and optical risk characteristics to output associated vulnerability result and time to effect for solid state laser weapon systems. JLaWS considers the effect of weather on laser propagation by automatically downloading weather files from established services to account for location dependent weather conditions. JLaWS allows the user to calculate optical risk in the event of HEL reflections from targets using the High Energy Laser Risk Assessment Tool (HELRAT). HELRAT graphically portrays the risk distances around a target that contains reflected laser radiation levels that could cause ocular hazards to friendly forces in the area. Figure 10 shows a JLaWS graphical rendering of a ship-based Laser Weapon System engagement with an unmanned aerial vehicle target

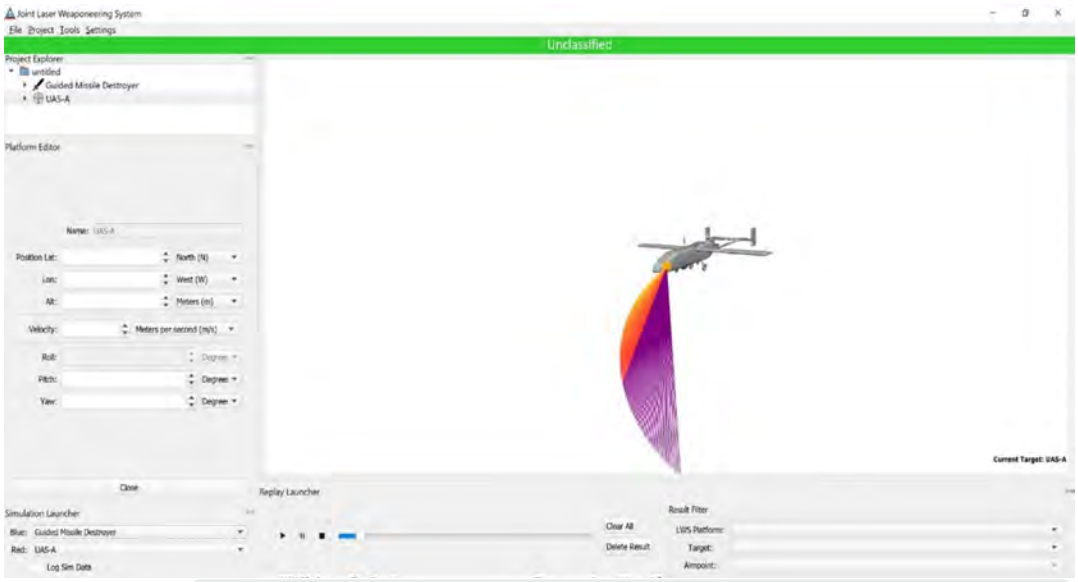

Figure 10. JLaWS Vulnerability Explorer and examples of shot lines

and the spherical zones around the target, as calculated by HELRAT, in which ocular hazards exist.

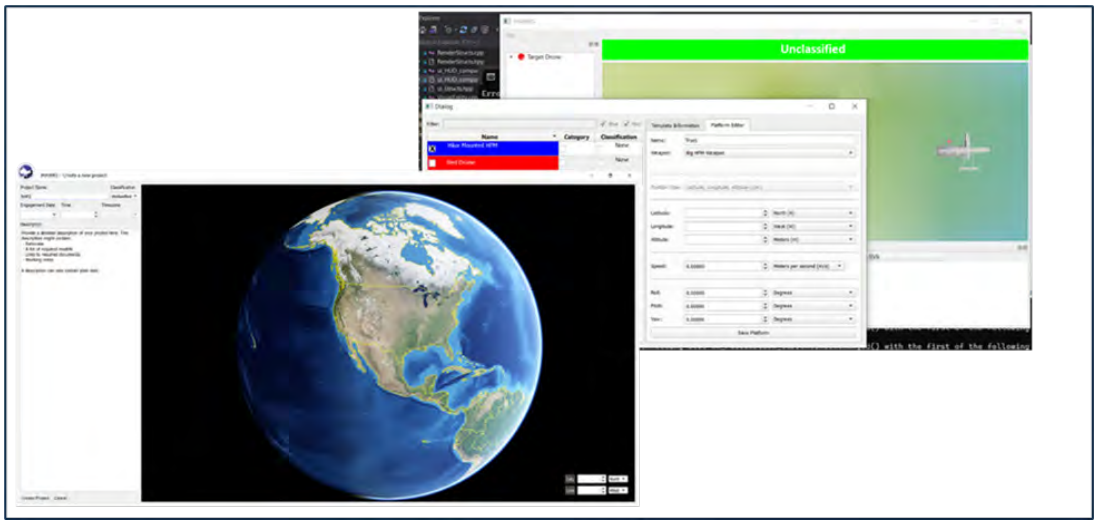

Figure 11. JHAWKS Initialization and Platform Editor

JTCG/ME placed a heavy emphasis on validating and verifying both the underpinning methodology and data that supports JLaWS. A tri-Service Methodology Review Committee made significant strides toward completing accreditation of JLaWS v2.4. The JARVIS repository was updated to include the ability to review and approve HEL target vulnerability packages; as a result, several packages are undergoing joint review. Moreover, multiple LWS characterization packages are nearing tri-Service review completion. The result of these efforts will ensure JLaWS provides the warfighter with a credible means to support weaponeering and CDE for HEL weapon systems.

Further development and validation of the surrogation tool allows for subject matter experts to generate efficient, reliable, and tractable HEL surrogate vulnerability packages from an existing database of completed assessments. Since a full vulnerability assessment is a time-consuming process, quick turnaround HEL analyses and studies can now be performed using the Characteristic-based Laser Objective Surrogate Evaluation tool.

JHAWKS

To advance the development and fielding of HPM weapon systems, JTCG/ME, and JLF partnered to conduct live fire testing, which generated lethality data to verify and validate dynamic engineering-level modeling for effectiveness of HPM weapons against small unmanned aircraft system swarm targets. Moreover, several lethality tests against Service-specific targets were conducted to identify and fill data gaps. Historically, HPM weapon systems testing has focused on effects based on 'back door' attacks where the signal couples to electronic components by entering seams or gaps. Vulnerability tests were conducted to assess damage from a 'front door' attack where the signal can couple into targets via intentional ports such as antennas. These tests aided in the development of new vulnerability methodology for front door target elements.

JTCG/ME made significant progress toward M&S tool development and defining processes that will enable JHAWKS use by the warfighter. A JHAWKS beta version included a GUI for ease of engagement setup (shown in Figure 11) and power-on target determination for free-space wave propagation scenarios. Enhancements were made to the Effectiveness Tool Box, an engineering-level M&S tool, that fills capability gaps for accurately modeling HPM dynamic engagements with multipath considerations. Atmospheric and terrain effects were incorporated into the Effectiveness Tool Box and a major overhaul to the graphics allow for the analyst to visually interpret the complexities of HPM wave propagation (shown in Figure 12). Credible engineering-level M&S outputs are required to provide inputs to JHAWKS. Multiple foundational efforts included generation of a JHAWKS Software Requirements Document, as well as an Interface Control Document, to define the structure and format of the engineering-level M&S tool outputs, thereby ensuring successful future JHAWKS development.

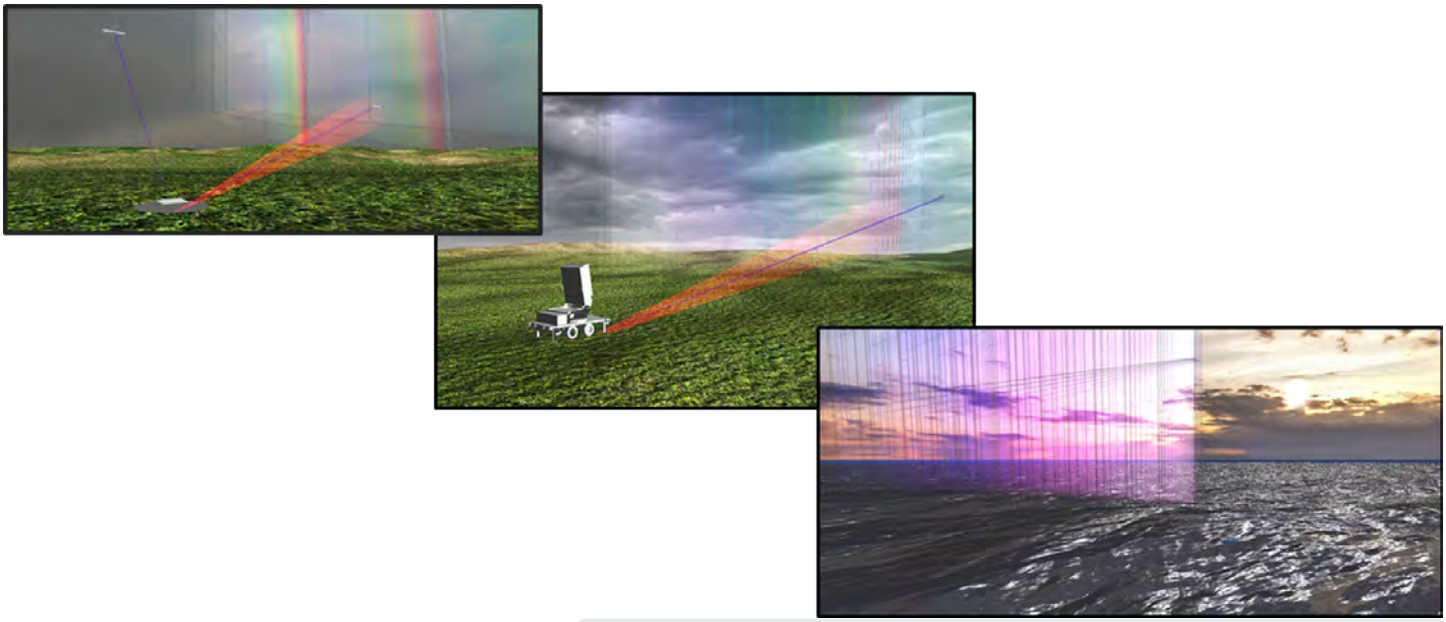

Figure 12. HPM Propagation for Land and Maritime Environments

Cyber Operations Lethality and Effectiveness (COLE)

In FY24, JTCG/ME's Joint Non-Kinetic Effectiveness team continued the development and fielding of cyber JMEM capabilities for the warfighter. The COLE tool is the foundational product, enabling commanders and decision makers at all echelons to generate accredited, quantitative, and predictive effects of cyber operations for combined joint all-domain operations. The COLE software provides the user with a cyber operations planning and analysis capability for; offensive cyber operations, test and evaluation of operational systems, and risk assessments of cyber resilient systems.

JTCG/ME deployed v3.4 of the COLE tool on both classified and unclassified networks, enabling planning elements to model cyber networks, characterize properties, and determine potential network vulnerabilities to cyber capabilities and TTP in various combinations for cyber operations and cyber capability requirement development.

Major FY24 COLE improvements include new automated data ingestion capabilities to accelerate and simplify network characterization and an attack-path optimizer that automatically generates possible courses of action, increasing the thoroughness of options and speeding analytical efforts via automatic generation and tracking of options. A new simultaneous actions capability has also been deployed, enabling planners to consider actions against multiple nodes from a single source. COLE's new functional modeling application allows users to see impacts of cyber operations on cyber-reliant functions. Finally, for COLE users focused on T&E or defensive cyber operations, the COLE team has developed a beta capability to assess risks to a network based on potential adversary courses of action. In addition to cloud-based deployments, in FY24 JTCG/ME initiated deployment of stand-alone COLE instances (known as 'COLE-in-a-Box') to support users who conduct cyber M&S and planning on closed or advanced program networks.

JTCG/ME continues to team with the JASP on the Machine Assisted Exploitability Simulation and Testing for Resilient Operations effort to further develop COLE's ability to assess cyber vulnerabilities of U.S. platforms. COLE for T&E provides a framework of models and tools to aid in examining aircraft cybersecurity.

JLF continues to develop Enhanced Vulnerability Discovery abilities to assist in rapidly and automatically characterizing, discovering, and reporting cyber vulnerabilities within complex software configurations through the Cyber Automated Threat Discovery and Vulnerability Evaluation Reinforcement (CADAVER) program. CADAVER is intended to leverage AI/ML to

allow identification of potential vulnerabilities to mitigate cyber-attack access points through automated and semi-automated means. Combined, COLE and CADAVER ensure warfighters have the necessary tools to assess cyber effectiveness/vulnerability using tri-Service-approved data standards and streams.

In FY24, JTCG/ME continued to team with the DoD Test Resource Management Center to create cyberspace effects and enabling Capabilities Cyberspace Live-Fire Evaluation Framework (CLEF) to provide a realistic test environment for cyber capabilities generating accredited performance data. Four CLEF servers have been installed at the 346th Test Squadron at Joint Base-San Antonio, Texas, with initial operating capability expected in September 2024. The CLEF effort will set the standards for rapidly generating and analyzing cyber performance, analogous to kinetic area testing capabilities and standards for fragmentation.

Influence Operations

In FY24, JTCG/ME Joint Non-Kinetic Effectiveness continued its pathfinder effort to develop and influence operations JMEMs, aimed at assessing how an adversary may respond to proposed military courses of action. Behavioral influences analysis can help inform how the U.S. applies military force or other instruments of power and identify what specific adversary elements to attack. Sandia National Laboratories has been developing the Dynamic Multi-Scale Assessment Tool for Integrated Cognitive-behavioral Actions (DYMATICA) tool to assess how various populations and groups perceive U.S. actions. Focusing primarily on aggregating and assessing unclassified, publicly available journals, news media, social media sources and academic papers, DYMATICA leverages AI-engines and subject matter expertise-informed ML models to forecast adversary responses to U.S. or coalition actions across all phases of operations to help influence the decisions of adversary leadership.

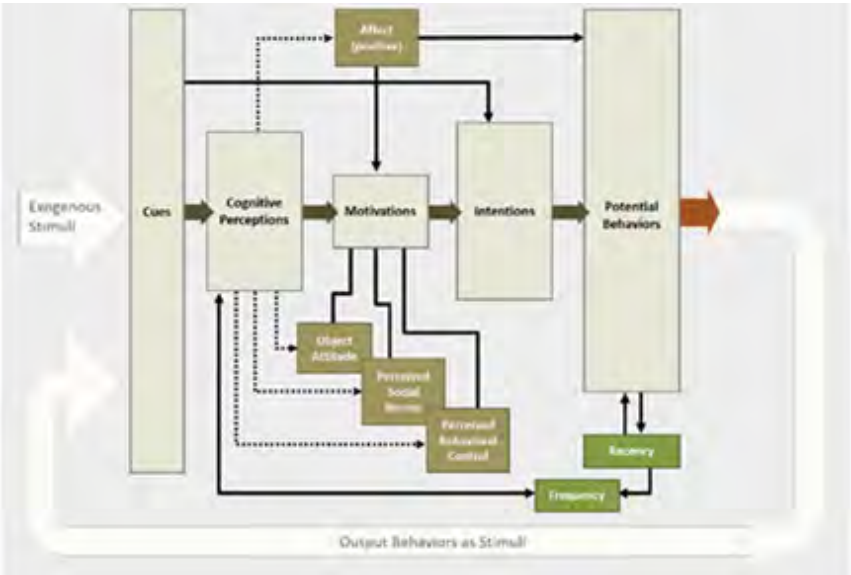

Figure 13. DYMATICA Workflow

EMS Fires

In FY24, JTCG/ME developed an initial set of JMEM capabilities to enable notional mission planning and execution in contested, congested, and constrained EMS environments. Moreover, preliminary modeling of systems across the Services was completed. These tools will estimate electronic attack (EA) effects and the ability of the warfighter to effectively prosecute adversary targets in contested, congested, and constrained EMS operations (shown in Figure 14).

JMEM for EMS fires will allow mission planners and targeteers to assess weapon and combat effectiveness in the presence of adversary EA (e.g., GPS denial and its effect on kinetic weapon guidance systems). It will also estimate the effects of friendly EA capabilities against adversary targets (e.g., jamming), which creates a foundation of joint standard EA effectiveness data and models used across the Joint Targeting Cycle. The objective by 4QFY25 is to expand modeling within an advanced framework that will dynamically depict high fidelity EA interactions to inform future Joint EA Predictive (JEAP) tool development and integration efforts.

JTCG/ME and JLF partnered to execute a full live fire drop of 6 GPS-guided weapons in a heavily denied environment. Testing

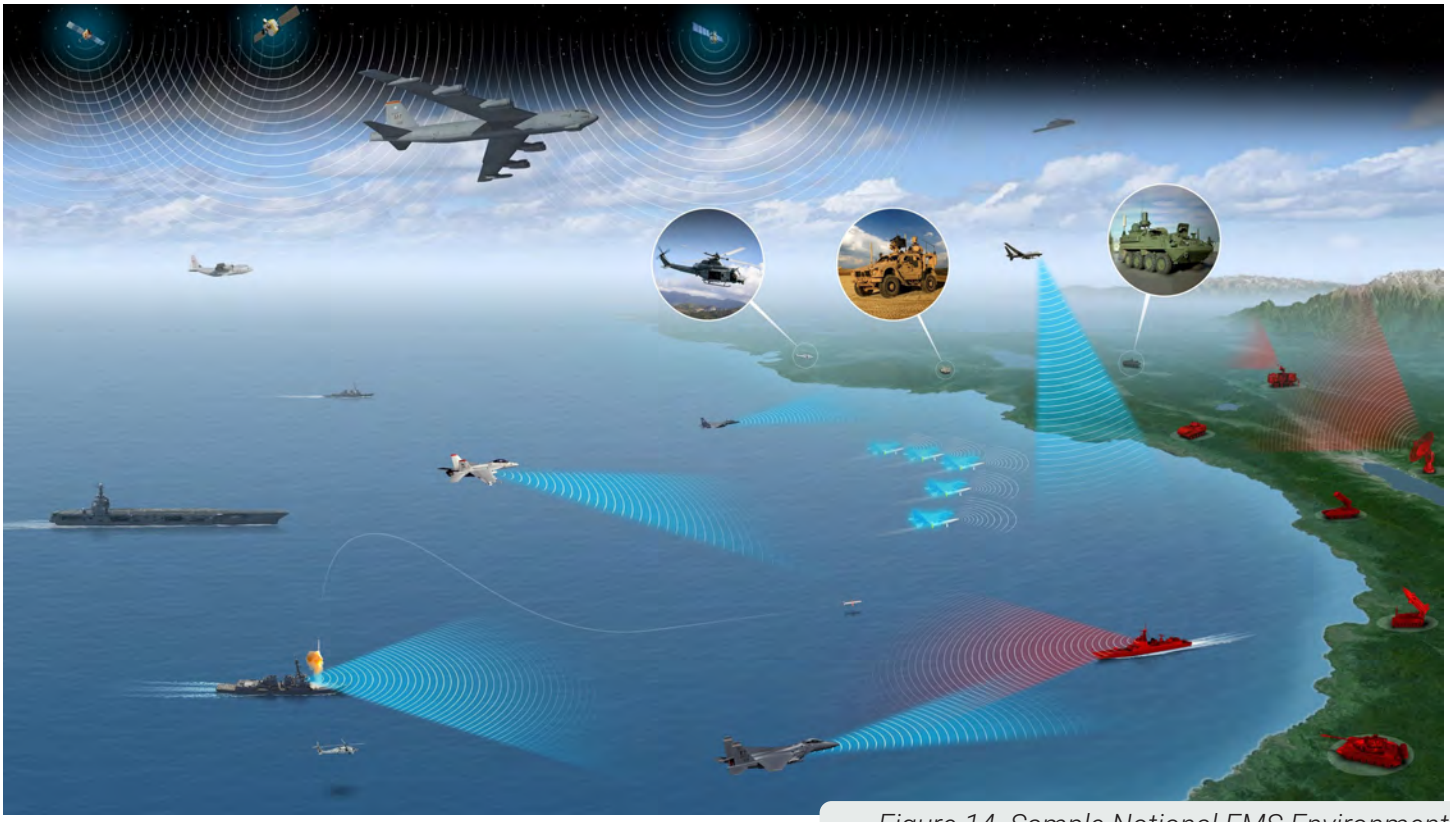

Figure 14. Sample Notional EMS Environment

was conducted in September 2024, leveraging the existing U.S. Army Position, Navigation, and Timing Assessment Experiment. The resulting data will inform current GPS guidance capabilities and improve M&S for predicting GPS guidance performance.

» SUPPLYING WEAPONEERING TOOLS TO SUPPORT INTEROPERABILITY WITH U.S. ALLIES AND PARTNERS

In FY24, JTCG/ME provided weaponeering tools and data sets in support of training to 10 partner countries under Foreign Military Sales agreements. This included the release of weapon effectiveness tables, collateral effects radii tables, and advanced target development capabilities that will help minimize collateral damage and reduce civilian casualties. These efforts directly supported the Presidential Conventional Arms Control Policy to build partner capacity and prevent civilian casualties. A second effort supported information exchange forums via information exchange annexes with coalition partners. These exchanges facilitate collaboration with partners on methodologies and efforts of mutual interest in weapons effectiveness and CDE for both kinetic and non-kinetic weapons. In FY24, JTCG/ME continues to prepare multiple information exchange annexes, to provide weapons effectiveness analytical exchanges and to expand the scope of topics to better represent complex strategic and operational environments.