TEST AND EVALUATION RESOURCES

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Test and Evaluation Resources

DoD T&E infrastructure must facilitate reliable and thorough performance evaluations of weapon systems in operationally representative environments. However, current deficiencies in T&E resources adversely impact the ability of DOT&E to fulfill its statutory mission. In turn, these deficiencies hinder the Department's ability to perform adequate T&E.

To keep pace with the threat capabilities in the modern multi-domain operational environment, the DoD needs to make significant and steady investments in T&E range modernization, including for threat surrogates and instrumentation. However, range restrictions, security, safety requirements, and cost limit the amount of live testing that is practically achievable. Investments are needed to maintain and update verification, validation, and accreditation (VV&A) of modeling and simulation (M&S) environments to augment live testing.

The T&E workforce is essential to plan and execute the adequate T&E required for performance assessments of DoD systems. DoD should invest in hiring, training, and maintaining sufficient workforce across the Service operational test agencies and other T&E organizations, especially in specialized or emerging technical fields like space, cyberspace operations, software engineering, data analysis, and artificial intelligence (AI). A well-trained and resourced T&E workforce is better equipped to accomplish its mission and adapt to emerging threats and technologies.

RANGE MODERNIZATION

The DoD lacks simulated (e.g., Joint Simulation Environment [JSE]) and open-air multi-domain infrastructure (e.g., numbers and types of target surrogates) necessary to assess weapon systems' performance in realistic combat environments. These combat environments involve collaborative and synchronized command-and-control networks that connect sensors to shooters across domains and networks. Since both U.S. systems under test and adversary systems employ these networked environments, the networks must operate at multiple classification levels. These multi-level classification capabilities introduce additional cost and complexity to the execution of test events. The DoD needs long-range test infrastructure that can be rapidly activated and configured to support complex mission scenarios involving air, land, sea, spectrum, cyber, and space systems.

» OPEN-AIR RANGES

Existing laboratories and range systems do not sufficiently represent current or future threat laydowns and operational scenarios. Test ranges should emulate system capabilities, tactics, and operating space that define the existing and future threats to characterize performance of systems under test. The current open-air range space should be expanded to better support system of system assessments of air, land, and sea combat systems

with capability for emerging long-range fires, hypersonic missiles, electromagnetic spectrum (EMS) warfare, and directed energy weapons (DEW). Necessary improvements include connecting U.S. test and training ranges via secure networks; acquisition of high fidelity, rapidly reprogrammable, open-air threat emulation systems; and upgrades to current high-fidelity systems, like the Radar Signal Emulator systems procured by DOT&E in 2014, to provide greater flexibility and fidelity.

The Air Force demonstrated use of Open-Air Battle Shaping (OABS) during recent operational testing. In addition, the Navy has been demonstrating OABS over the past few years during T&E events that span both the test and training communities as well as multi-Service events. OABS includes instrumentation and systems used on open-air ranges, aircraft, and threat systems. OABS provides real-time integration of live aircraft and ground threat systems with modeled weapon performance to provide real-time kill removal to simulate the results of air-to-air, air-to-surface, or surface-to-air engagements in mission-level, force-versus-force, scenarios. Data collected by OABS are critical for VV&A of M&S and essential for the fidelity of JSE.

The Services should improve OABS by adding more entities such as red and blue aircraft, ground threats, and weapons. Additional improvements to monitor data link/network connectivity among players and across multiple test ranges to use modern weapons engagement methods are required. Improved virtual threat insertion, such as missile launch effects and self-protection electromagnetic warfare (EW) techniques add operational realism in a contested environment. Finally, a kill/survive determination methodology to support upcoming operational testing of additional aircraft systems.

In addition, there are shortfalls in the reliable collection of time, space, and position information (TSPI) from participating platforms at open-air ranges. The quality of TSPI collected in tests and in large-force exercises varies from range to range and, in some cases, from platform to platform in any given test event. This shortfall impedes post-test analysis by making it difficult to reconstruct ground truth in aircraft testing.

The open-air test ranges available for operational testing of EMS-dependent systems also lack adequate instrumentation for capturing and reconstructing the many RF signals present in a test. Mobile RF collection instrumentation is required that can be sited with ground-based radar, communications, and jamming systems employed in an open-air test to capture truth data for the signals emitted by these systems. Inadequate instrumentation often precludes both determination of and validation of causes of performance shortfalls in EMS systems under test and validating digital models of EMS systems.

In addition, none of the U.S. test ranges presently have sufficient numbers and variety of RF emitters and surrogate systems capable of replicating peer threat capabilities for radar jammers, GPS jammers, and data link jammers. Surrogates for each of these threat capabilities are essential for T&E of the end-to-end effectiveness of platforms and their weapons. This shortfall limits the ability of the DoD to represent a modern threat environment with realistic signal density and congestion and is common across all EW system assessments.

» LONG RANGE MISSILE TESTING

The DoD requires long-range, overland missile flight test corridors with land-based impact areas to support test flights of missiles with extended ranges. Currently, longer-range oversea flight tests use both broad ocean area and land masses as impact areas. However, neither produce the required lethality data against threat-representative targets at operationally required ranges. The Test Resource Management Center is exploring overland corridors to mitigate this shortfall. The corridors need to increase capacity to support the testing of new hypersonic weapons and use of hypersonic-specific range instrumentation for terminal area and lethality assessments, including mobile data collection assets. OT&E and LFT&E need tools to analyze terminal area scoring data collected during flight tests. These tools support effectiveness decisions on engagement outcomes and are inputs

to mission-level simulations that assess lethality of hypersonic missiles and interceptors.

In addition, the Missile Defense Agency (MDA) requires a replacement for the Pacific Tracker and Pacific Collector missile range instrumentation ships that are nearing end-of-life and are essential to provide ground truth telemetry and flight termination functions for flight tests of all MDA programs and other missiles. The MDA will also require shipboard radar upgrades for these assets and is exploring courses of action, but a funding gap remains.

THREAT AND TARGET EMULATION

The T&E community is struggling to characterize system performance against representative threat scenarios and threat surrogates of representative physical size, quantities, and sophistication. The DoD requires substantial resources to keep pace with the rapid development of adversary threats and ensure that Intelligence Community-validated threats are available to the T&E community. Development of more complex target laydowns would enable more realistically stressing conditions for testing the operational capabilities of systems under test and the performance of operational units employing these systems.

» AIR

Piloted Aircraft for Mission-Level OT. In combat versus peer-level adversaries, DoD aircraft can be expected to encounter large numbers of advanced threat fighter aircraft with capabilities comparable to their own. The DoD's aggressor units lack a sufficient number of aircraft, with sufficient electromagnetic systems capabilities, to be able to represent threat fighter aircraft in open-air, mission-level, operational test trials. These threat surrogate aircraft must be equipped with active, electronically scanned array radars that are fully integrated with advanced, digital self-protection radar jammers. Moreover, these aircraft require integrated, air-to-air electro-optical (EO) and infrared (IR) sensors and communications data links, with capabilities comparable to those of advanced threat fighter aircraft, and data recording instrumentation to satisfy T&E analysis requirements.

Airborne Targets for Live Weapons Testing. The availability of threat surrogate full-scale targets for live, air-launched weapons testing is insufficient to assess lethality and validate models for end-to-end effectiveness for missiles. Planned testing may include limited or no full-scale targets due to test asset availability limitations. Surrogate targets are required for fourth- and fifth-generation threat fighter aircraft, large bomber and mobility aircraft, helicopters, and others. These targets should have physical sizes, radar cross sections, and IR signatures comparable to the threat aircraft they need to represent. They should include electronic attack (EA) and radar emitters that replicate the full RF spectrum, power, and angular coverage of these threats.

Air Defense Fixed-Wing Aircraft. The Army lacks organic fighter aircraft to support testing of air defense sensors and systems and relies on agreements with the Navy or Air Force to provide that support. Fixed-wing aircraft are needed to evaluate target tracking, identification, and survivability to electronic attack for air defense sensors and systems. Previously, Air Force fixed-wing aircraft stationed adjacent to White Sands Missile Range provided support along with associated airborne jamming and identification, Friend or Foe. These assets have been relocated and are no longer available. The Army is currently pursuing agreements with Air Force and/or Navy for this support as well as leveraging large test events for Integrated Fires Test Campaigns (including for Guam Defense System) to gain fixed-wing support from the other Services.

Hypersonic threat surrogates. OT&E of hypersonic missile defense will require increasingly sophisticated hypersonic threat surrogates and targets that can represent cross-range and terminal maneuvers. The MDA is developing Aegis Sea-Based Terminal and GPI capabilities to address these types of threats. The Navy's supersonic aerial targets, the GQM-163, cannot fly evasive maneuver flight trajectories representative of supersonic anti-ship cruise missile threats nor can they fly the aggressive diving profiles of some anti-ship cruise missiles. The Navy, similar to the MDA,

also requires a hypersonic threat surrogate that is usable in terminal defense scenarios.

The Navy is investigating solutions to address this capability gap. The maximum range of the GQM-163 is not large enough to demonstrate some Navy kill-chain and missile capabilities. These shortfalls limit DOT&E assessments of air and missile defense systems which are intended to defend against such threats, their associated defensive combat systems, and their host platforms that need to survive against such threats. Flight testing against realistic threat surrogates provides data to evaluate hypersonic missile interceptors and to support V&V of high-fidelity and hardware-in-the-loop M&S.

» SEA

Diesel Submarine. Diesel-electric submarines represent important threats that are smaller than U.S. submarines, have different maneuvering and acoustic characteristics, and are capable of resting on the sea floor. To properly evaluate torpedoes and antisubmarine warfare capabilities, the Navy needs a mobile target that can accurately represent a diesel-electric submarine.

Torpedo Countermeasure Representation. The Navy currently uses U.S. countermeasures for torpedo testing that operate differently from foreign threat countermeasures. To accurately determine and maximize torpedo performance against other nation's submarines, the Navy needs static and mobile submarine-launched countermeasure surrogates that can emulate threat capabilities.

Weapons Set-to-Hit Target. The Navy conventionally conducts torpedo testing in a set-not-to-hit mode, with the unarmed weapon passing safely above or below the target submarine and lacks a capability to evaluate final approach and impact on the target hull, known as set-to-hit testing. The Navy is currently investigating the use of older submarines, which are about to be decommissioned, as representative set-to-hit targets that are mobile and reactive. The ability to evaluate this final stage of torpedo attack is required to accurately determine lethality and effectiveness of the torpedo against threat submarines employing full evasion capability. The Navy needs to build a full-size autonomous submarine surrogate that can provide representative response in both maneuver and countermeasure employment.

Self-Defense Test Ship (SDTS). Navy ships and combat systems must be able to defend themselves against anti-ship cruise missile attack if they are to survive in armed conflict. Test range safety restrictions do not permit aerial targets to fly close enough to or directly at Navy ships to allow for operationally realistic self-defense testing so the Navy has traditionally used the unmanned SDTS for close-in self-defense evaluation. The SDTS is a decommissioned Spruance-class destroyer that can be equipped with the combat systems of various ship classes and operated via remote control. Aerial targets can be flown close enough to the SDTS to evaluate performance within proximity to the test platform that cannot be accurately determined from other testing. The current Navy SDTS is planned to support self-defense testing for multiple classes of ship programs. The Navy is actively working to overcome shipyard delays and additional funding costs to assure SDTS availability and prevent delay of future test programs. The Navy expects these issues to be resolved by early 2025. The Navy has yet to determine SDTS capability for follow-on platform and system evaluation including future improvements to the Aegis Combat System. To support adequate testing, the Navy should identify and develop an SDTS capability, which could include further extension of the existing SDTS, that supports upcoming testing, as well as future ship-class and combat system programs.

» LAND

Ground-based Air Defense Replication. The ground-based air defenses of peer-level adversaries are multifaceted and multilayered, involving kinetic defenses, EA defenses, and DE point defense weapons. Major shortfalls exist in each of these domains. Surface-to-air missile (SAM) sites are one of the key classes of ground targets for U.S. aircraft and air-launched weapons, as well as key threats to these aircraft and weapons. Despite initiatives to enhance the open-air range infrastructure for threat radar EA and DEW emulation, shortfalls remain

because adversaries continue to rapidly advance and expand their capabilities. The DoD requires additional investment in high-fidelity emulation of threat EA and DEW systems.

In addition, the DoD requires additional investments in radar test assets capable of high-fidelity emulation of signal detection and tracking capabilities of advanced threat radars. These radar assets should be associated with specific SAM systems and the wider integrated air defense systems that support SAM employment. For each of the aforementioned threat systems, test ranges should have sufficient numbers of moveable vehicle shells to physically represent the threat system vehicle types accurately, with reflectivity properties, coatings, and camouflage netting typical of those employed.

MODELING & SIMULATION

As adversary threats and system capabilities become more complex, the DoD has struggled to develop and maintain validated M&S. The rate of adversary threat development is currently faster than the pace of high-fidelity M&S threat model development. As a complement to live testing of physical systems, there is increased effort in the DoD to pursue digital M&S solutions that represent current capabilities of systems under test and of the threats they need to be tested against in joint environments. Validated M&S solutions are necessary to support the end-to-end assessment of systems, particularly in cases where the system cannot be demonstrated for operational, cost, or security reasons.

Integrated Air Defense. The evaluation of integrated air defense systems will require a joint M&S environment to provide the end-to-end performance of numerous sensors, shooters, and command and control networks developed across the Army, Navy, Air Force, and MDA. This capability will require integration of M&S tools developed across the Services.

Missile Defense Systems. The MDA needs to develop a system-level, high-fidelity digital modeling venue to allow quantitative assessments of the effectiveness of integrated hypersonic and ballistic missile defense systems. The MDA began development of the End-to-End Digital Integrated System-level Simulation in 2018 but recently terminated funding for that effort. Even with the right test corridors and instrumentation, there will be flight safety and cost limitations that make high-fidelity M&S essential.

Joint Simulation Environment. Limitations in open-air range infrastructure caused the Navy and Air Force to explore incorporating additional weapon systems into the JSE to enable testing and training that cannot currently be conducted on the DoD's major test and training ranges due to technical (i.e., threat complexity or density) and security reasons. The JSE requires additional blue and red platforms, emitters, and weapon types to simulate a "night one" fight against a peer-competitor or near-peer-competitor adversary. Shortfalls exist in JSE with regard to current and future representation of surface-to-air, air-to-air, and naval threat capabilities. The recently established joint Navy and Air Force JSE Governance is working to overcome these shortfalls, but technical, programmatic, and cost obstacles remain.

Autonomous Systems. Maritime autonomous systems have a large range of sensors. Perception of their environment is dependent upon below or at surface operation. Attaining confidence in the autonomy based on this perception requires significant assessment of capability within a decision-rich environment that is time intensive and challenging with live testing alone due to safety constraints and the pace of operations. Development and assessment of these systems will be accelerated with credible synthetic range capability that supports hardware-in-the-loop and software-in-the-loop evaluation within operationally representative conditions. Investment is required to fully characterize the perception of the employed sensors across the spectrum of operational environments.

Anti-Ship Missile and Launch Platforms. The Navy needs M&S of anti-ship missile and launch platform threats to support operational testing for ship combat systems, EW suites, and ship missile systems. The Navy lacks validated threat models to determine systems performance across the range of threats. Recent shipboard EW programs had only two intelligence-community validated threat models available for operational test. The Navy also has no

M&S representations of the foreign radar systems which provide the pre-launch targeting information to anti-ship missiles. Without models, DOT&E cannot assess how well systems perform against such threat radars.

Cyber. Assessing the DoD cyber survivability and resilience would benefit from accredited simulation environments to evaluate mission effects caused by cyber-attacks that have been demonstrated through other testing. Without exercising the mission in the presence of a given cyber effect, it is not possible to assess end-to-end system performance.

EMS OPERATIONS

The electromagnetic operating environment (EMOE) is increasingly congested and contested by military and civilian systems and constrained by national and international regulations. In addition, modern software defined EMS-dependent systems can rapidly change their operating characteristics. Future adversary EMS-dependent systems will include complex, autonomous behavior (incorporating AI to varying degrees) that will adapt to changing environments as the systems learn. The Threat Systems Management Office developed the Ground Electronic Warfare T&E Roadmap that provides a time-phased investment plan to fill Army and Marine Corps EW T&E gaps. This plan, however, does not address EW T&E gaps required to test in a multi-domain environment.

The inability to represent modern radars affects T&E of EW systems and their associated combat systems and platforms. Emulating the closed-loop tracking capabilities of modern threat radars, including software-defined radars, remains a shortfall. This shortfall critically affects the ability to conduct adequate operational testing of our Electronic Attack (EA) capabilities. Additionally, it affects the ability the test EA capabilities to support their host platforms' mission. Most of the radar emulation capabilities on the test ranges and in laboratory facilities emulate only the open-loop signal emissions of threats, and not the sophisticated back-end processing, including electromagnetic protection logic, that these radars employ.

Other key EMS-related shortfalls are focused on our emulation of threat electromagnetic attack systems. For example, the current set of anti-ship missile surrogate (aerial target) payloads do not sufficiently represent foreign electromagnetic attack systems for use in testing a program's electromagnetic protection. While the Navy has improved their ability to represent such threats, advancements in these capabilities have not yet been fully integrated into aerial targets. This issue affects all variants of shipboard air and missile defense systems, and host platforms. Another key shortfall is in the ability to conduct frequent and simultaneous GPS jamming and spoofing across multiple test ranges, at times due to FAA regulations.

In addition, adversaries are fielding passive radars utilizing the emissions from commercial transmitters, which need to be emulated in test. Including emulations of all types of neutral emissions in OT&E is critical to assessing the DoD ability to operate in complex military and commercial electromagnetic environments.

Potential adversaries have a diverse set of capabilities to detect U.S. units across a broad set of operational environments. The DoD must be able to fully characterize the susceptibility of U.S. troops and friendly units to the detectability of acoustic, visual, IR and electromagnetic emissions by our adversaries. These characterizations require a combination of M&S-, laboratory-, field-, and operational testing.

DIRECTED ENERGY WEAPONS

The DoD lacks facilities to safely test High Energy Laser (HEL) weapon systems in realistic combat conditions. DoD initiatives are required to outfit test and training ranges with HEL-specific safety equipment to conduct open-air, self- and area-defense test scenarios with weapons expected to produce HEL beams. Radar, IR and EO sensors will also be needed throughout the engagement zone to collect data on target position, velocity, reflected irradiance, and battle damage for assessing performance.

The Army's White Sands Missile Range is developing requirements to upgrade its HEL Systems Test Facility. Current operations are limited to testing one

system at a time and do not support test in multi-domain operations. The upgrades would provide DE and counter-DE, as well as comprehensive integrated air and missile defense T&E capabilities. Future open-air tests of Navy shipboard self-defense HEL systems will need accredited threat surrogates for anti-ship cruise missiles and swarming unmanned airborne and surface vehicles. Finally, the DoD lacks test ranges with surrogate systems capable of replicating peer threat capabilities for tactical lasers, high-power microwave, or ultra-wideband DEW point defenses to assess end-to-end effectiveness and vulnerability of airborne platforms.

CYBER

Emerging Cyber Command capabilities for cyberspace operations, including those that are part of the Joint Cyber Warfighting Architecture, will require novel, range-based resources to assess the ability of the cyber operational force to monitor activity, issue orders, and engage across the spectrum of friendly, neutral, and adversary cyberspace. These resources include ranges with neutral and malicious traffic, scenario generation capabilities, and digital copies of cyber operational force mission systems to support OT&E while the primary systems support real-world operations.

DoD Instruction O-3600.03, "Test and Evaluation of Cyberspace Effects and Enabling Capabilities," aligns testing requirements for cyberspace effects and enabling capabilities (CEEC) with traditional acquisition requirements for non-cyber capabilities to ensure that CEEC are effective, suitable, and survivable in their intended operational environments and against intended targets. Current CEEC testing requires additional investment in opposing force emulation to create operationally realistic attack surfaces.

Cyber OT&E relies on appropriately trained adversarial testers, DoD Cyber Assessment Teams (DCAT), and DoD Certified Red Teams (DCRTs) to act as aggressors. Demand for adversarial cyber testing is increasing. The DoD should ensure these teams are fully staffed and trained on emerging cyber threat tactics, techniques, and procedures. DCRTs/DCATs also require collaboration environments to share information and jointly develop tactics, techniques, and procedures. Digital and physical collaboration spaces should exist at all necessary classification levels.

Cyber test teams lack sufficient expertise in several technology areas where cyber threat actor capability is out-pacing our ability to defend, including:

- Cloud systems supporting software development, hosting user-facing applications, or housing national defense data
- Networks using non-traditional protocols, including automotive and aircraft controls; weapons systems (e.g., firing, targeting); radio communication; satellite communication; hull, mechanical, and electrical; supervisory control and data acquisition; and industrial control systems
- Systems that exchange vital mission data via RF interfaces
- AI and machine learning-based approaches to cyberspace attack and defense

These limitations constrain the DoD's ability to understand system performance and survivability against a peer or near-peer threat actor.

NUCLEAR MODERNIZATION

The DoD requires full funding to support upgrades to critical T&E infrastructure that supports nuclear modernization programs. Test chambers at proper classification are needed to support development and testing of the various nuclear effects as associated with DoD Instruction 3150.09, "Chemical, Biological, Radiological, and Nuclear Survivability."

AI AND AUTONOMY

Testing AI and autonomy (AI&A)-enabled systems requires expanded processes, networks and instrumentation to cover the larger operational space required to assess model generalizability. More workforce expertise in software integration and data analytics are needed to collect, integrate, store, reduce, and analyze enough data to quantify

performance and risk. Testing survivability against adversarial attacks and addressing unintended bias and unexpected performance for AI&A functions will be necessary to adequately evaluate AI&A systems.

Data infrastructure is a major enabler for T&E of AI&A-enabled systems for automated and real-time data collection, reduction, and analysis. Big data analytics and large knowledge management systems are required to improve the quality, speed, and depth of post-mission data processing. In addition to data collection infrastructure, system and platform agnostic data collection tools will be required. The Joint Mission Environment Test Capability program is building out the network infrastructure to support operations across integrated test ranges, and wide area off-range exercises and experimentation events. SkyRange is advancing instrumentation needs across larger operational spaces using modified Global Hawks as instrumentation platforms. Cloud Hybrid Edge-to-Enterprise Evaluation and Test Analysis Suite (CHEETAS) is closing gaps in collecting, integrating, storing, and analyzing the data. The B-52 upgrade programs and hypersonic weapons testing recently demonstrated the use of CHEETAS for managing and transporting data faster.

The Chief Digital & Artificial Intelligence Office seeks to address a lack of AI&A tools, but increased emphasis needs to be placed on educating test agencies, programs, and field organizations on what tools exist and how to use them. Numerous efforts are underway across the Services, including the Air Force's VISTA X-62A testbed that facilitates evaluation of AI&A aircraft capabilities; the Army's Combat Vehicle Robotics technology integration program to address capability gaps on robotic and autonomous platforms; and the Navy's Naval Autonomous Test System that creates a simulation framework for testing autonomous systems.

SPACE

To increase resilience of U.S. space operations, communication and missile defense programs will place many more satellites into orbit performing various missions, increasing the importance of adequate T&E for these systems. Tests conducted on-orbit need high-fidelity space-based threat surrogates and range instrumentation to collect data from testing and transmissions to ground-based command-and-control systems. The space environment will also need to be emulated in space simulation chambers to replace or supplement on-orbit testing, especially for survivability evaluations from lasers, high power microwaves, and kinetic attacks. When on-orbit tests are impractical, evaluations can use full motion mission simulators and simultaneous reproductions of the natural and man-made environments.

Space test and training ranges – including the National Space Test and Training Complex (NSTTC) – are being developed to connect space-based resources with open-air and laboratory-based hardware-in-the-loop simulation environments. NSTTC, under the authority of Space Training and Readiness Command (STARCOM), is envisioned to provide resources for T&E in EW, cyber, DE, kinetic, and nuclear environments.

The DoD needs qualified personnel to operate test assets, analyze data, and conduct tests on new space systems and technologies. STARCOM and Space Delta 12 lack experienced T&E personnel and funding needed for adequate OT&E of programs under DOT&E oversight. These shortages impede comprehensive assessments of operational effectiveness, suitability, and survivability.