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US Army Wingman Joint Capability Technology Demonstration (JCTD): Initial Soldier and Marine Feedback on Manned–Unmanned Gunnery Operations

by Kristin E Schaefer, Ralph W Brewer, Anthony L Baker, E Ray Pursel, Brandon Gipson, Steve Ratka, James Giacchi, Eduardo Cerame, and Kristin Pirozzo

NOTICES

Disclaimers

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14. ABSTRACT

This report is part of the Wingman Joint Capabilities Technology Demonstration program. During the week of 22–26 October 2018, two crews (one Soldier crew and one Marine crew) participated in a joint manned–unmanned teaming exercise to evaluate training and operation during gunnery operations on a live-fire range. This report provides the general feedback on the Wingman program training, teaming, robotic technology, and design of the Warfighter Machine Interface display. Specific advancements related to robotic vehicle technology, the displays, and training are reported.

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Summary

The larger scientific community is developing processes for accurate and appropriate training and assessment of human–robot teams. One of the main difficulties in identifying these methods is the lack of real-world robotic systems that require the interoperability of the team to meet set performance metrics. During the week of 22–26 October 2018, two five-man crews (one Marine crew and one Soldier crew) performed real-world manned–unmanned teaming conducting live-fire gunnery evaluation exercises for the Wingman Joint Capability Technology Demonstration program.

The five-man crew was located onboard a Command and Control vehicle and operated a separate weaponized unmanned Robotic Wingman vehicle. Both vehicles were the High-Mobility Multipurpose Wheeled Vehicles. The Warfighter teams first used the Robotic Wingman simulation testbed for training prior to operating the real-world Robotic Wingman vehicles during multiple gunnery operations on the Carmouche Range located at Ft Benning, Georgia. Operations included observation of a full live-fire demonstration conducted by the engineering team, and the Soldier and Marine teams engaged in dry-fire, blank-fire, and stationary live-fire conditions.

Following the events, the Warfighters provided feedback related to training and their experiences with the various aspects of the exercises. This report provides the Warfighter feedback to support the development of appropriate training, technical needs for the simulation testbed to support effective training, and interaction with the real vehicles, controllers, and Warfighter Machine Interface displays.

1. Introduction

The US Army seeks to identify current and emerging technologies and projections of technology-enabled concepts that could provide significant military advantage during operations in complex, contested, or congested environments between now and 2028. These include advanced technologies that support integration of joint manned–unmanned teaming (MUM-T) initiatives. As unmanned technologies advance from traditional teleoperation to more interdependent operations with advanced autonomous decision-making capabilities, it is essential to develop appropriate collaboration between the human and autonomy-enabled team members (Phillips et al. 2011). For effective teaming to occur, throughout the development life cycle of the technology, it must include human team members to advance the potential for trusted team development. A driving reason for this focus on the human element in MUM-T operations is that effective teaming and appropriate use of the technology depend on the human's understanding of the system, its behaviors, and the reasoning behind those behaviors (Chen et al. 2014). If human expectations do not match system behaviors, people will question the accuracy and effectiveness of the system's action (Bitan and Meyer 2007; Seppelt and Lee 2007; Stanton et al. 2007). Such skepticism can lead to degraded trust which, in turn, can be directly linked to misuse or disuse of the system, even if it is operating effectively (Lee and See 2004; Schaefer and Straub 2016).

1.1 Wingman Manned–Unmanned Teaming

The US Army Robotic Wingman program provides a real-world example for understanding manned–unmanned teaming that occurs throughout system development. The goal of the Wingman program is to provide advanced robotic technologies as well as experimentation to assess and demonstrate increased autonomous capabilities for joint manned and unmanned ground combat vehicles. The team currently consists of a five-man crew on the Command and Control (C2) vehicle (left side Fig. 1) comprising the manned vehicle driver, vehicle commander (VC), long-range advanced scout surveillance system (LRAS3) operator, robotic vehicle operator (RVO), and robotic vehicle gunner (RVG), paired with a single unmanned weaponized robotic ground vehicle (right side Fig. 1).

Fig. 1 Image of the real-world manned vehicle (left) and robotic weaponized vehicle (right)

Mobility operations are being developed to support multiple levels of autonomy including control-by-wire or teleoperation, waypoint finding, and semi-autonomous driving via defined go/no-go zones, leading to advanced autonomy. In line with most research discussions on levels of autonomy (e.g., Parasuraman et al. 2000), it is unlikely that the RVO will maintain only a single type of control authority throughout a gunnery mission. Therefore, a goal for effective teaming is to assess the capability of the operator to appropriately toggle between control authority modes with respect to team or mission needs. What we aim to limit are inappropriate changes in control authority, or misuse of the system, due to added stress, workload, fatigue, or a degradation in trust. To reach this end, the operator must have accurate and appropriate task, mission, and environmental information from the other human team members as well as from the Wingman vehicle.

Unlike mobility operations, there has been very little research in unmanned gunnery operations. Gunnery operations require interaction between members of the manned crew and the robotic vehicle's mobility and fire control system (FCS). The autonomy-enabled features of the FCS include detecting potential targets within the weapon's field of view, tracking user-selected targets, and keeping the weapon trained on those targets while applying a ballistic solution. The human team members are still responsible for any user-applied adjustments and the global decision-making associated with firing on a target. The VC ultimately authorizes engagement of a target, and the RVG is in the loop for the actual trigger pull. Due to the limitations in the current research, there is a specific need for research to characterize the complexities in detecting, identifying, and engaging targets revolving around sensor and networking delays and the limited operator situation awareness (SA) inherent in unmanned weapon systems.

Team coordination and performance are closely related (Salas et al. 2009), and effective communication results in improvements in other team processes and outcomes (Mathieu et al. 2000; Kozlowski and Ilgen 2006). Efficient team communication is critical for target engagement given the coordinated nature of gunnery operations. Since Wingman adds multiple types of autonomy to the equation, it is even more important to understand how team communication relates to performance, given that human–agent interaction still lacks the fluidity of human–human interaction (Bisk et al. 2016). As such, there is a need to test our methods for analyzing team communication to ensure they are applicable to the human–agent context.

Further, performance is a direct result of the MUM-T interoperability, where the manned vehicle is often located at a remote position with respect to the Wingman vehicle, which can be outside of direct line of sight. Therefore, in support of prior research (see Chen et al. 2014; Schaefer et al. 2017c), a technical solution for providing shared SA amongst the human team and with the robotic combat vehicle (RCV) is key to effective teaming. Accomplishing this goal rests with the development of the Warfighter Machine Interface (WMI), which provides interactive customizable displays for the VC, RVG, and RVO (Fig. 2). Each Wingman WMI has access to shared SA data, categorized by subsystem across the bottom of each display, including major subsystems such as map, sensor, and alerts. The map screen provides an interactive aerial image, MIL-STD-2525B symbols (1999), mobility plans, sensor fields of view, and grid reference lines. The sensor screen provides live video feeds with overlays providing SA such as azimuth, elevation, heading, and field of view. The VC and RVG use the sensor feeds to positively identify potential targets for engagement. Each WMI also has SA data available in a common toolbar and prioritized alerts visible as pop-ups at the top of the screen.

Fig. 2 Example of the three WMI displays for the commander (left), robotic vehicle gunner (center), and robotic vehicle operator (right)

1.2 Wingman Simulation Testbed

The Wingman simulation testbed uses a software-in-the-loop design whereby all the same vehicle software is accessible in a tabletop configuration to support team training prior to operation on the real-world vehicles. Specific technical details outlining the development of this simulation testbed can be found in ARL-TN-0830 (Schaefer et al. 2017b), ARL-TR-8254 (Schaefer et al. 2017a), and ARL-TR-8572 (Schaefer et al. 2018). More information on how the simulation testbed supports human–agent teaming can be found in Brewer et al. (2018). The current instantiation of the simulation testbed supports all five crewstations (Fig. 3), including the three WMI displays for the VC, RVG, and RVO, and the controllers for the driver, RVG, RVO, and LRAS3 operator.

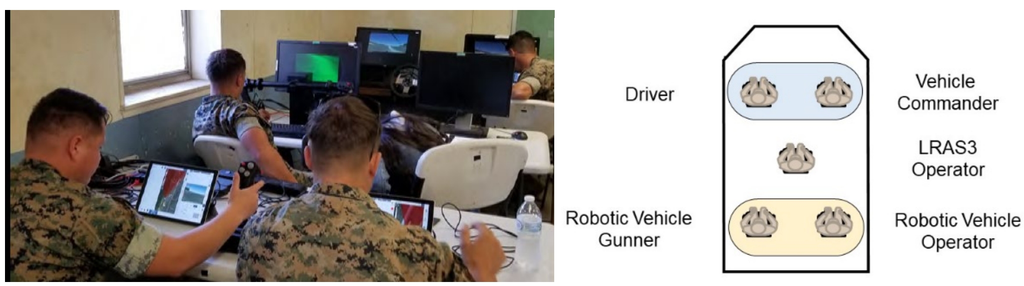

Fig. 3 Simulation testbed at Fort Benning, Georgia (left); crewstation layout in the C2 vehicle (right)

The design of the RVG crewstation supports the actual gunner handle, as well as a gamepad and joystick for when the actual handle is not available (Fig. 4 for button layouts).

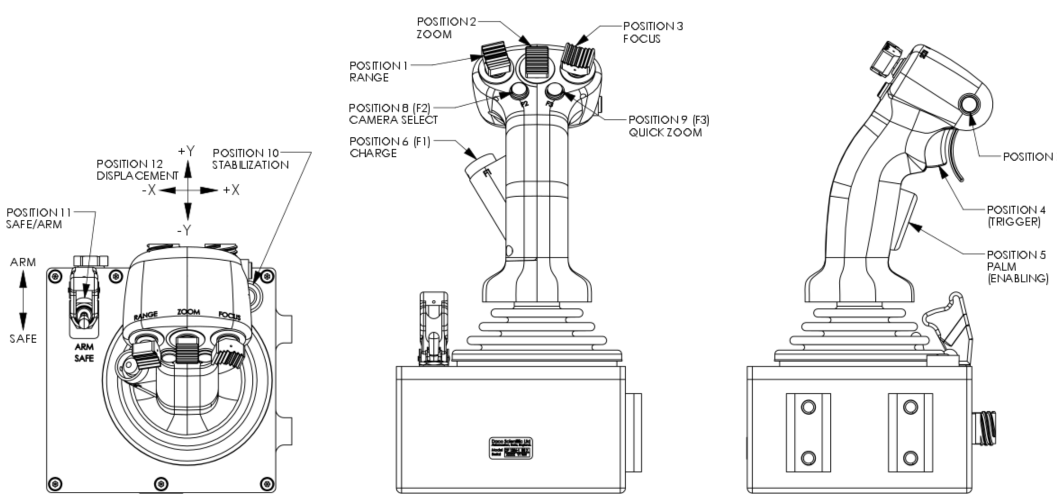

Fig. 4 RVG control grip and button layouts.

The RVO crewstation supports a gamepad controller matching the use of the gamepad controller in the actual vehicle (Fig. 5).

Fig. 5 Gamepad controller for the RVO crewstation

The C2 vehicle driver crewstation supports a Logitech gaming wheel and pedal controller. The LRAS3 operator crewstation supports a gamepad and the LRAS3 handgrips designed by Night Vision labs. Button configurations and layouts for the LRAS3 operation can be located in the *PdM Ground Sensors MWO Self-Training Guide for LRAS3 Operation* (MCoE 1996). The gamepad controller button layout is provided in Fig. 6.

Fig. 6 Gamepad controller layout for LRAS3 operator crewstation

For training purposes, the virtual environment used was the gunnery range from Camp Grayling, Michigan. This terrain was generated using real-world terrain elevations from the US Geological Survey and has been aligned between the software of the two game engines. In addition to duplicating the terrain geometry, targets from the Camp Grayling range are duplicated in position and behavior to provide targets for detection and engaging. The full training program is described in Section 2.3.3.

1.3 Soldier and Marine Event

The purpose of this data collection was to get Soldier and Marine feedback on the training and team operation to conduct gunnery exercises with a manned–unmanned team. These teams were the first Warfighter teams to ever operate the Robotic Wingman platform. Outcomes from this study should inform future training, features of the RCV, and development of the WMI to support future MUM-T operations.

1.3.1 Crews

Two crews participated in this study: the Marines from the 1st Marine Logistics Group Combat Skills Training School (CSTS) and the Soldiers from the 3rd Squadron, 16th Cavalry Regiment. An engineering team member filled the role of the C2 vehicle driver for both crews. The Warfighters filled the remaining four crewstations.

The selection of the CSTS Marines for the Wingman Joint Capability Technology Demonstration (JCTD) was based on their experience and expertise on machine gun team operations, concept of employment, and employing tactics, techniques, and procedures (TTPs). As infantry subject matter experts, the CSTS Marines train Marines and Sailors in regiments, battalions, and companies across the Marine Logistics Group. Their primary focus is on combat training courses. These courses cover tactical leadership principles, machine gun functions, combat orders, and procedures to counter threats and mitigate risks to Marine forces conducting tactical convoys. Each of the four Marines who attended the JCTD has deployed in support of Combat Operations during Operation Enduring Freedom/Operation Iraqi Freedom.

The four Soldiers were selected from the 1st Squadron, 16th Cavalry Regiment, 316th Cavalry Brigade. These Soldiers hold the military occupational specialty of 19D, Cavalry Scout. They are proficient in reconnaissance, surveillance, and target acquisition, and subject matter experts in movement and maneuver. In addition, these Soldiers are a part of the 316th Cavalry Brigade, whose only mission is to run the courses training Cavalry Enlisted Soldiers (19D, 19K One Station Unit Training), Officer Courses (Armor Officer Basic Course), and Advanced

Reconnaissance Leader Training (Army Reconnaissance Course and Cavalry Leader's Course). As such, these Soldiers have a premiere pedigree to understand the TTPs necessary to fight and win on today's technologically advanced battlefield, especially the ability to move, shoot, and communicate. All of the Soldiers selected were also previously qualified on a Table IV, making them familiar with the exact requirements of the Wingman event.

1.3.2 Schedule of Events

- Monday, 22 October 2018: Classroom training, simulation training, and one dry-fire training exercise for each crew
- Tuesday, 23 October 2018: Observed engineering team's live-fire demonstration; Soldier and Marine crews each conducted one stationary live-fire exercise
- Wednesday, 24 October 2018: Soldier and Marine crews each conducted one blank-fire exercise and two dry-fire exercises
- Thursday, 25 October 2018: Soldier and Marine crews each conducted one dry-fire exercise and one stationary live-fire exercise

1.3.3 Training

A combination of classroom, simulation, and live field instruction on the gunnery ranges was used to facilitate crew training. Classroom training consisted of training from the Training Circular (TC) 3-20.31, *Training and Qualification, Crew* (DOA1 2015) and TC 3-20.31-4, *Direct Fire Engagement Process* (DOA2 2015). Simulation training was used to train the crew on respective crewstation roles, controllers, and user interface displays, as well as how to work together to engage targets using the Wingman system. Hands-on field instruction was used to practice gunnery operations on a live range working as a team with a real robotic system with direct support and direction from the engineering team.

For classroom training, understanding the crew engagement process is integral in determining how to effectively conduct live-fire gunnery evaluations. The training of the direct fire engagement process focused on the direct fire engagement commands. The discussion centered on the standard structure of the engagement process, the guidelines for executing conduct of fire, and the techniques that facilitate rapid and lethal engagements. The engagement process known as DIDEA is an acronym for Detect, Identify, Decide, Engage, and Assess.

The crew must rapidly acquire targets, identify them as potential threats, make a decision to engage or not engage a target, engage the target(s), and then assess the effects of each firing action. The crew initiates the direct fire engagement process with a fire command. The crews were trained on the different types of commands, the elements, and the terminology. These included an initial command at the beginning of an engagement; a subsequent command to continue engaging the same target; and supplemental commands to service a different target during the same engagement. The flowchart in Fig. 7 outlines when to use certain commands.

While the crew must know how to effectively engage a target, they must also understand the evaluation process. Crew evaluations for the manned–unmanned team are currently using the remote weapon station (RWS) evaluation process defined by TC 3-20.31-4 (DOA2 2015). The evaluation takes into account the posture (offense or defense), type of threat, posture of the threat, and the range of the threat. Evaluators will expose targets during a 50-s window in which the crew will have the opportunity to engage and destroy the target(s). Scoring consists of performance, timing, and team communication. Penalties are assessed for safety violations as well as minor infractions for the crew in response to commands during the engagement process.

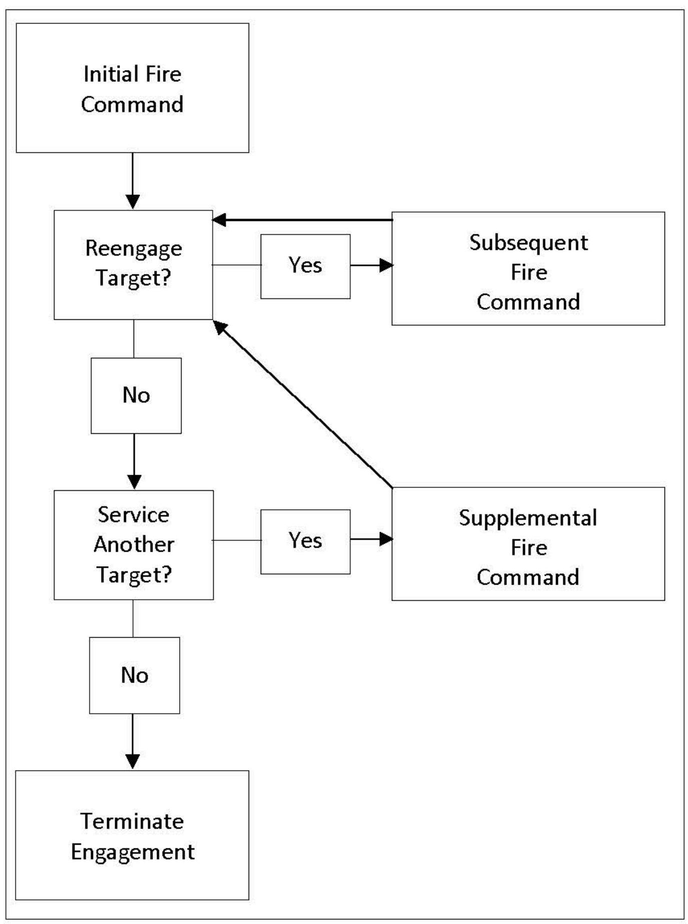

Fig. 7 Outline of when to use a type of fire command

The simulation provided a benign environment in which each crew member was given one-on-one hands-on training using the controllers and WMI display. This was followed up with practicing offensive and defensive engagements on a virtual gunnery range from Camp Grayling, Michigan. Both manuals and guided practice from the engineering and development team were used to train controller functionality (i.e., button location and use) to lase targets (LRAS3 operator), control teleoperation of the RCV (RVO), and engage targets (RVG). Similarly, individualize instruction was provided to train the features, capabilities, and tasks required to operate the RCV and communicate between the crew using the WMI displays for the VC, RVO, and RVG. Manuals were provided as reference materials for each WMI station. Crews training with the simulation provided an initial opportunity to practice the concepts on team engagements learned during the classroom portion of the training during multiple simulated offensive and defensive engagements.

Live field training included three main events. First, each crew member was given an individualized review with the engineering team on their role, responsibilities, controllers, and WMI capabilities. Second, the LRAS3 operator and VC were given the opportunity to go on the range with the C2 driver with an engineering team member on board the vehicle and the gunnery evaluator on the radio. This training provided the opportunity for these team members to develop appropriate communication between the C2 vehicle crewstations outside of the direct DIDEA process. Training included identifying critical environmental features needed to improve team communication for mobility (e.g., location of battle positions) for the VC, and identifying and practicing lasing real targets by the LRAS3 operator. The third training event was a full vehicle crew walkthrough of all of the daytime engagements. The engineering team and evaluator were on the radio to provide step-by-step directions for running through a full engagement exercise and provided training on how to address technical questions and errors.

1.3.4 Dry-Fire Engagement Run

In a crawl–walk–run approach, the crews began by conducting evaluation exercises on the course without using any ammunition. The crews would go through motions of engaging the targets using the DIDEA process and dry firing the gun. This was important to synchronize their crew duties prior to adding ammunition to the process.

1.3.5 Blank-Fire Engagement Run

The blank-fire engagement runs were exactly the same as the dry-fire ones, except with the introduction of blank ammunition. When the gunner pulled the trigger, the gun would fire the blanks and retort, giving the gunner a more realistic view of what is seen using live ammunition. The timing of completing the engagement relied entirely on the sensing of the target by the VC (as was the case with the dry-fire engagement runs).

1.3.6 Stationary Live-Fire Engagement Runs

Once the Soldiers and Marines were sufficiently trained and evaluated with dry and blank fire, they were allowed to take part in the stationary live-fire engagement run. The stationary live-fire engagements were similar to the dry- and blank-fire engagement runs with two differences. First, the crews used live ammunition. Second, to comply with an Army Test and Evaluation Command safety memo restricting live fire while moving, the RCV was chocked to prevent vehicle movement while the weapon was loaded. Defensive engagements did not change, but offensive engagements were changed to reflect traffic control points. A traffic control point engagement treats the evaluation as an offensive one with regard to timing, but the vehicle does not move.

2. Feedback

Warfighters were given multiple opportunities to provide feedback throughout the week. This included individual written feedback and group discussion on the training, and daily group after-action reviews with directed questions. The following subsections describe the training-specific feedback, MUM-T operations feedback, and WMI recommendations and requests for future display options.

2.1 Training Overview

Overall, both teams felt that the classroom, simulation, and hands-on training with the vehicles provided different but important capabilities. The classroom training provided general instruction for the tasks, ranges, and team interactions. The simulation training provided initial orientation to the WMI displays and controllers, and an opportunity to practice team communication. Hands-on directed training with the actual vehicles on the range provided a more in-depth orientation to the team operations and the ability to practice what was learned during other training sessions.

It was clear to both teams that the simulation did not directly match the real vehicle. There were three major differences:

1) The RVG crewstation handle from the vehicle was not available for use during training. Therefore, the RVG had initial practice with a gamepad

controller that had different button presses and different sensitivity than the actual controller.

2) The simulation handle for the LRAS3 station was not as sensitive as the real system. The LRAS3 operator had to continue to hold the simulation handles in place to maintain directionality (otherwise it would auto-return to center). The real system would stay in place.

3) The simulation testbed had the Autonomous Remote Engagement System (ARES), which added autonomy features that supported gunnery operations (i.e., autonomous slew-to-cue features) that were not activated on the real vehicle. Both teams found this technology to be incredibly helpful and wanted to use it on the actual vehicle.

In order to match the real-world system, engineers updated the software on the simulation testbed prior to the first day of training. The update to the Robotic Technology Kernel (RTK) and the Autonomous Navigation Virtual Environment Laboratory were updated on 1 October 2018. ARES was updated to version 18.4-dev on 17 October 2018. The Unity server and clients were updated to version 4.2 and the WMI software updates on 19 October 2018. As a result, there were some integration issues that occurred in simulation during training. As an example, the incorrectly configured RVG WMI was having issues communicating with ARES. This resulted in an initial inability of the RVG to select targets or slew to an LRAS3 cue.

2.2 Training Feedback

The following subsections outline the written feedback from each participant specific to the training program. Each subsection includes a response to how this feedback could be addressed in either the training program or the technical development of the Wingman system.

2.2.1 Areas for Improvement

1) Three out of eight participants felt the training was adequate and had no direct feedback on how to improve training.

2) Two participants requested more hands-on training and practice with the real-world vehicles. This was in part due to the previously listed deviations between the simulation and the real system.

3) There was one request for a more in-depth orientation on the weapon system and vehicle configuration.

4) Two participants requested more "free form" or flexible training across multiple test courses, with multiple target options. Overtraining a single scenario can overbuild confidence.

5) There should be opportunities to practice potential events and errors that could occur on the range. For example, what to do when the robotic vehicle loses communication with the C2 vehicle, or how to address issues that the robotic gunner noticed, such as the camera would jump when he would arm the system.

The following procedures, training specifications, and technical developments describe current work being done to address this feedback:

1) To account for variations between simulation and the real system, procedures have been requested to have an earlier system development stop time to allow for the simulation development team to have time for integration and testing prior to training.

2) Additional classroom training, including videos and manuals, is being developed to provide a more in-depth orientation on the weapon system and vehicle configuration.

3) The simulation development team is currently integrating virtual environments for the Ft Benning Multipurpose Range Center gunnery ranges for scripted Table VI exercises, as well as more unscripted virtual environments so Warfighters can get a more realistic feel for the future capabilities, such as supporting a complex breach scenario.

4) Training is being revised to provide better instruction on handling different types of events and errors. The best medium for training depends on the type of errors. The Wingman team is currently looking at identifying the best training protocols to account for this task.

2.2.2 Positive Feedback

Overall, all participants felt the training was successful. Use of classroom, simulation, and range time together, with a focus on hands-on learning rather than lecture, promoted effective team training rather than individual understanding alone. Having a subject matter expert on hand to answer questions at the time of an issue (rather than just at after-action review) improved retention on how to use the controllers, displays, and the system more appropriately. There was a request for more dry runs on the real system and a recommendation to keep the crews together through all the training, even when something was role specific; this helps the team understand the requirements of the other team members.

Participant feedback supports the importance of having classroom, simulation, and live training, as each provides a different type of learning experience. Additional multimedia resources are currently in development to support team operations and role orientations. All future training will keep the crew together, whenever possible, for all aspects of training.

2.2.3 WMI Display Questions

All participants felt confident using the WMI displays for interaction with the Wingman RCV following training. There were no direction questions or requests for clarification. Two questions were posed. First, after using the slew-to-cue autonomy features in the simulation, participants requested use of this feature on the real vehicles. They felt that it would greatly improve performance. The second question was a technical question requesting a way to interface between the LRAS3 and the RVG cameras. The feeling behind this was with that type of extra technology, the LRAS3 operator could support added shared SA when identifying and tracking multiple targets.

In response to the participants' questions, slew-to-cue is an option from the RVG crewstation. However, due to technical issues with the elevation at this event, it was not providing accurate referencing and therefore is not recommended for use on the real system. To assist with shared SA for targeting purposes, the VC has the capability to both the RVG and LRAS3 video feeds. For safety purposes, only the gunner is able to slew the weapon system.

2.2.4 Controller Questions

Following training, there were no questions about the different controller features or buttons. There was, however, a request for future technology to improve classification of friendly versus hostile targets. Since this classification process took a great deal of time for the VC to edit on the WMI, it was requested to find a way for the LRAS3 operator to lase targets as friendly, hostile, or other.

The LRAS does not assign a designator to the target that it lases; the VC can use the WMI to assign the level of threat, as well as specific features about the target, using MIL-STD-2525. The current design of the WMI is designed so that users of the WMI can change its features manually.

This feedback has the potential to influence how the Wingman WMI is designed. Having users interact with the interface gives the developers much needed feedback on how the user interface will be utilized and its overall usability. If from feedback it becomes obvious users are missing how to use part of the interface, that portion will be reevaluated. This allows the team to decide if it is graphical or a training problem. Additionally, if many users request similar features, it could indicate to the designers that the current implementation might need to be updated with said feature.

2.3 MUM-T Operations Feedback

Notes written by the experimental team and audio recordings of the after-action reviews were reviewed and compiled into the following feedback areas. The feedback is separated as crewstation-specific and team communication.

2.3.1 RVO Crewstation

Two major comments specific to waypoint following were provided regarding the RVO crewstation. First, one operator reported that on the first day, he had trouble starting a waypoint plan and dropping points, stating that the process was not intuitive. While this process was demonstrated during one-on-one training with simulation and practiced with team operations, this comment suggests that more training is needed prior to operation in the field. Additional training material is also being developed to provide "how to" manuals and audio-visual training tools.

The second comment was that waypoint placement is offset and not consistent when operating the real system. This is a technical issue with the real system. To correct this issue, the map widget on the WMI will need to incorporate more accurate vehicle localization. It was also noted that there was some difficulty in creating and editing waypoint paths in a moving C2 vehicle. Additional testing was done on-site with a stylus but was found to be more difficult than using a finger on the touch display.

A request was made to be able to program multiple routes (e.g., primary, secondary, tertiary) and switch between these routes. The current design of the WMI allows a person to create and save plans that can later be recalled from a file. However, having this additional on-screen visibility or transfer of paths could advance the Wingman future capabilities. The WMI development team is currently looking into the technical capabilities to support this type of feature function.

2.3.2 RVG Crewstation

Multiple comments were specific to controlling the weapon system, accessing camera sensors, and accessing autonomous support for weapon system control:

1) The location of the arming switch on the handle required two-hand operation or removal of the hand from the joystick. It is standard practice to

disarm the weapon system between engagements and firing positions. This increased time and frustration with the controller.

2) Every time the palm was clicked while ARES was running, the gunner camera jumps. The sudden shift in position can disorient the user and requires the gunner to manually return to the position prior to the jump. In addition, the gun sometimes jerks upward when removing the safety.

The operators' standard procedure of disarming the RWS after every engagement, including between targets in a single engagement, was not a concept of operation considered by the development team. Disarming the Picatinny Lightweight Remote Weapon System (PLWRWS) and then depressing the palm switch (as one would to move the mount while disarmed) causes the PLWRWS to enter "surveillance mode", which super-elevates the weapon while maintaining the current cameral elevation. This is the designed behavior. A result is that switching between armed and disarmed, then, will cause the weapon and the camera to move, which will also cause the operator's video to jitter. Surveillance mode was disabled in the vehicle's remote weapons station firmware; the simulation training system will be updated to match.

3) The RVG requested the option to switch between thermal and other camera sensors.

The gunner's station has the ability to pull up all of the sensor feeds. However, the RVG was instructed to only pull up the LRAS and the weapons system because the other feeds could cause encoder conflicts on the real vehicle. This can be rectified with a video server, but our video server is currently under development. In addition, there was not a day camera available on the PLWRWS sight package.

4) There is sensitivity in the handle making it difficult to manually adjust targeting. When on target, the gunner wants to lock to target and for it to stay. Further, after using ARES in simulation, the RVG wanted the autonomous slew-to-cue for real engagements.

The sensitivity and responsiveness of the handle to move the RWS while teleoperating is inherently a manual process (continuously adjusting the sensitivity as range changes) and is an ongoing effect. The "correct" settings seem to be tied directly to the operator's workflow. If the operator relies heavily on selecting targets on the WMI and letting ARES move the mount to and then track the target, this is less of an issue than when an operator is more reliant on his own ability to manipulate the weapon through teleoperation. Both styles should be possible, and determining how to best enable or balance them requires further study.

5) Some additional recommendations were made for specific WMI features to support gunner operations. These included the capability to create a path for the gun to rake while shooting; shot targets to be removed from the gunner map; a notification when the weapon encounters (or clears) a malfunction; and the addition of a second camera with a wide point of view to allow for scanning the environment when not engaging targets.

Current discussions are underway with JCTD partners to determine which of these features are possible to integrate and what could be included in the current development plan. For example, to increase the capability to increase SA, the WMI can support an eight-camera 360° SA sensor system (demonstrated in other programs). However, these sensors are not currently part of the Wingman platform. Additional updates to the menu books now include documentation on how to reference both the weapon and gimbal status to determine potential weapon issues.

2.3.3 LRAS3 Operator Crewstation

Following training, the LRAS3 operators identified some concerns with the controls in the simulation testbed. They noted that the LRAS handle was too jumpy or jittery at times, which made focusing on precise targets difficult. In addition, the simulation controller snaps back to a zero position when there is no force applied to it. This does not match the actual system, which stays in the orientation where it was left. It was also identified that the laser range finder was oversensitive and would send multiple battle space object (BSO) symbols to the WMI displays for a single identified target. This behavior only happened on the controller and not on the gamepad. Finally, the operators made a suggestion for the simulation to allow switching to a night mode in order to match the functionality on the actual LRAS3. They also recommended that it would be beneficial for team performance to allow the LRAS3 operator the capability to designate a target as friendly or hostile—the current process for this designation takes the VC multiple menus and button presses on the WMI display.

Based on this feedback, it was determined that the LRAS3 handle for simulation was not a suitable interface for training with its current capabilities. The physical constraints of its joystick-like movement mechanism included a physical spring that returns the mechanism to center, causing the resolution of the movement encoder to be insufficient for fine movement at high zoom levels. This was distracting enough to the operators to be considered a detractor from training. In addition, there is currently only one of these controllers and plans for several training systems. Therefore, the simulation development team is looking into alternative options to the LRAS3 handle.

To address the remaining comments, planned future LRAS3 operator station development includes implementing the night camera and display. Implementation of the LRAS3 menu system could enable additional functionality including the ability for the operator to label a target as friendly or hostile.

2.3.4 VC Crewstation

The major comment regarding the VC crewstation was specific to the threats list. Currently, the list of targets gets reordered during an engagement. The VC requested an option to maintain a consistent order despite the arrival of new targets.

In response to this comment, there are current features within the WMI to support this request. There are multiple ways to sort the threats list. In addition, new or incoming targets can be added to the beginning or end of the list. Additional testing will be conducted to identify alternative sorting methods, and the processes will be included in future iterations of training.

2.3.5 Team Communication

There were three major comments about team communication. First, there was a recommendation for more training on team communication between the crew members. It was noted that "most firefights are over in 10s" and that communication is the key to speeding up operations. Second, more information is needed in relation to communication with the RCV. General instruction on the physical parameters should be included in training (e.g., is line of sight necessary?). It was also requested to have some way to visualize the effective communication range between the C2 vehicle and the RCV on the WMI display. Third, more effective error messages are needed when communication breaks down. Currently, no instructions are provided on how to reestablish comms. Only an error message is displayed stating that comms went down.

In response to these comments, additional training will be provided to practice crew communication, identify RCV capabilities for communication (i.e., approximately 1 km) and communication ranges, and identify and recover from errors. Within the WMI, the error message will be revised to define crew response. For example, when communication is interrupted, a message will state that the crew needs to wait until the system reestablishes communication. In addition, the RTK currently has support to identify lost communication policies that are not currently being used in Wingman. Additional testing will be conducted to see if there are any alternative methods for reestablishing communication.

2.4 Feedback Specific to the WMI Display Design

Feedback on all the WMI displays has been divided into general feedback and widget-specific feedback (camera sensor, map, and BSO).

2.4.1 General WMI Comments

1) Users appreciated the height and position of screens on the real vehicle. It allowed for visibility over the screen and through the windshield when necessary.

2) It was not obvious how to adjust window sizes within the WMI.

Training manuals are being updated with a reference guide on widget placement, and training during the classroom and simulation session will be revised to include specific guidance. The capability to move widgets on the WMI allows for individual preferences. Therefore, users will need some time to practice with the display to identify an ideal configuration. From a technical goal, the WMI development team is working on a way to save this layout customization.

3) When working with the real system, the VC noted difficulty with the screen registering touches in cold weather (approximately 55° F).

Additional testing is needed for cold weather testing to stress the WMI and identify its limitations.

4) Users identified a time that the command vehicle icon did not move on the WMI.

The WMI is designed so that all assets move on the map widget. The only time an asset would not move on the map widget is if the RTK software was not functioning, there were lost comms, or there was a localization problem.

2.4.2 Camera Sensor Widget

1) Sensor screens are too small.

There is currently an aspect ratio that calculates the sensor screen size. However, alternative options for customization are being explored by the development team to account for “wasted space” on the video screens.

2) Commander requested controls to adjust view clarity of the sensor screens similar to that of existing thermal optics that have controls to allow adjustment of contrast and some other features.

The WMI currently has support to control the gain, brightness, and contract of a sensor; however, only the main operator (not the viewers) has this capability. Additional training will be included to demonstrate to users how to control these features.

2.4.3 Map Widget

1) Users wanted the ability to “pinch and zoom” instead of being constrained to using the slider to zoom in or out on the map or the real vehicle.

There are currently different options for this type of feature within the WMI. The WMI development team will test these features with the current displays to determine the best functional design.

2) Users requested contour lines on the map to aid in judgments of elevation.

This feature is not currently supported in the WMI, but it is a possible future feature.

3) Users requested a visible scale on the map to aid in judgment of distances.

The current version of the WMI supports this feature, but it was not operational during this event. This feature will be tested and included in training.

4) The range fans for the vehicle, gunner, and LRAS3 need to be accurate for better coordination between the crewstations. In addition, the range length should match the capabilities of the sensor (not extend indefinitely). Users also requested a toggle switch to turn on or off the range fans. Sometimes they obstructed the view on the map.

The WMI development team is testing these features. There was a bug in the version that was used during this event that caused the range fan to be too large and too dark in color. A toggle option is being developed.

2.4.4 BSO

1) Users requested the option to customize phase lines with different colors and names.

The current design of the WMI allows for customization of phase line names and thicknesses. The variation in coloration is a feature that is currently in development. Training during the simulation phase will include customizations on BSOs, including phase lines.

2) Identifying a neutral BSO as either a friendly or hostile target and adding additional features require a few different menus and multiple button

presses. It was recommended by the users that they be able to edit a BSO by selecting the object.

It is possible to include a "long hold" type option to pull up the requested menu features.

3) Vehicle fuel level would be highly practical for the VC to know.

This is a feature that is currently not instrumented on the Wingman vehicle.

2.5 Feedback on General Operations

This section outlines more general feedback regarding interactions with the Wingman systems and interfaces.

2.5.1 Situation Awareness and Battlefield Management

When asked, Soldiers and Marines reported no instances of information overload. To the contrary, they requested more information to help improve team and shared SA.

1) Users noted that there were no issues with voice communication between crew members.

2) It was requested to add in a small WMI display for the LRAS3 operator (if possible) to help maintain shared SA with the team. This would reduce the number of times the operator would need to reenter the C2 vehicle for additional direction or clarification.

3) Users suggested the inclusion of default layouts (or let users save layouts) for the WMI. This type of feature would allow users to return to these default layouts with a click of a button on the display. This helps prevent users from becoming overwhelmed when the display becomes too cluttered with docked and pop-up windows

4) Some specific features noted to improve SA include the change in color when the ammunition round count was low, and the capability to see multiple crew sensor screens concurrently (e.g., LRAS and gunner). These features supported team operations during target engagements.

5) VCs noted that the current C2 vehicle cannot effectively support dismounts. This restricts operational flexibility.

6) In a commonly recurring theme, there was a request for redundant systems, which would allow the crew to still drive and fire the robotic vehicle in the event of system failures.

2.5.2 Trust

Trust is a critical consideration when humans interact with automated systems. Ineffective systems can damage operator trust of their equipment and lead to later issues where systems are not used correctly, so it is important to understand how the Wingman crews perceive the effectiveness and safety of the robotic system. The following main trust issues were identified:

1) Multiple comments from crew members indicated that losing connectivity to the robotic vehicle damaged their trust of the system.
2) The RVO often felt underloaded and could have been assigned more tasks.
3) Users reported feeling unsafe with the weapon system due to reliability issues.

The full list of issues including team coordination, usability, and technical errors identified from recordings of crew operations is provided in Table 1.

Table 1 Issues Warfighters encountered during dry, blank, and stationary live fire runs

Date	Run	Crew	Type of issue	Actual issue	Engagement
22 Oct	Dry	Marine	Team coordination	Discussing commands for target engagement	Before 1
			Usability	Coordinate lasing and range finding with LRAS and RWS	Before 2
			Technical error	RCV not working, lost comms with RVO	During 3
			Technical error	RWS jumped when switching to “fire” (two times)	During 4 & 7
22 Oct	Dry	Army	Team coordination	Discussing incorrect lasing distance	Before 3
			Technical error	RWS jumped when switching to “fire”	During 4
			Technical error	RVG lase not working correctly	During 5
23 Oct	Live	Army	Technical error	RWS misfire (two times)	During 3 & 4[a]
			Technical error	Incorrect lasing and range acquisition	After 4[a]
			Technical error	Issue regaining control of RWS after e-stop	Before 4[b]
			Technical error	RVO WMI station issues: intermittently went blank, freezing, some problems with RCV movement	Before 6

Note: Each run had a maximum of seven engagement trials. Some of the engagement trials were attempted more than once due to an issue that may have occurred.

[a] First attempt of an engagement trial

[b] Second attempt of an engagement trial

Table 1 Issues Warfighters encountered during dry, blank, and stationary live fire runs (continued)

Date	Run	Crew	Type of issue	Actual issue	Engagement
23 Oct	Live	Marine	Technical error	RVG did not have control of the weapon	Before 3
			Technical error	RWS misfire	During 3[a]
			Team coordination	Discussing incorrect lasing distance	After 3[a]
			Technical error	Incorrect lasing and range acquisition (two times)	During 6[a] & 7
24 Oct	Blank	Marine	Technical error	RWS misfire (two times)	During 1 & 3
			Usability	Team requested to remove GoPro cameras from windshield due to obstructing visibility	After 1
			Technical error	VC WMI was "super pixellated"	During 3
24 Oct	Blank	Army	No issues noted	No issues noted	No issues noted
24 Oct	Dry	Marine	Team coordination	VC instructed RVO to move the RCV in a way that did not let RVG point the weapon far enough left; this led to team retrying the engagement	During 5[a]
24 Oct	Dry	Army	Technical error	RVG video sensor issues: intermittent freezing and "choppy" feed	During 3 & 4
24 Oct	Dry	Marine	Technical error	Lost comms: RVO lost connection to RCV, and lost ability to teleop RCV; IMU failed	Bounding to 3
24 Oct	Dry	Army	Technical error	RCV was moving unusually slow during bound	Bounding to 3
			Training	VC needed more training on accurate slewing of the RWS	During 3
25 Oct	Live	Army	Technical error	RWS jumped up on RVG's screen while "mid-trigger pull" (three times)	During 1 & 2
			Technical error	RWS fired at incorrectly high angle leading to engagement ceasefire	During 2
25 Oct	Dry	Marine	Technical error	RVG feed completely blurry when zoomed all the way in	During 3

Note: Each run had a maximum of seven engagement trials. Some of the engagement trials were attempted more than once due to an issue that may have occurred.

[a] First attempt of an engagement trial

[b] Second attempt of an engagement trial

Table 1 Issues Warfighters encountered during dry, blank, and stationary live fire runs (continued)

Date	Run	Crew	Type of issue	Actual issue	Engagement
25 Oct	Dry	Army	Technical error	Minor video freezes	Bounding to 3
25 Oct	Live	Marine	Usability	Before moving out to the first positions for the first engagement, the RVO reversed the RCV while at sensitivity 100 and nearly backed into the Safety vehicle	Before 1
			Technical error	WMI sensory screen freezing	During 6
			Technical error	RWS continues to fire after releasing the "safety" switch	During 6
25 Oct	Live	Army	Technical error	RVG did not have control of the weapon	Before 1
			Technical error	RVO had difficulty making RCV stay on path during teleop	Bounding to 3 & 5

Note: Each run had a maximum of seven engagement trials. Some of the engagement trials were attempted more than once due to an issue that may have occurred.
[a] First attempt of an engagement trial
[b] Second attempt of an engagement trial

2.5.3 Interaction and Control

The Wingman system is designed to support mobility and weapon system autonomy; however, teleoperation is trained and in place as a secondary method for controlling the RCV. For this event, only teleoperation of the weapon system was used. The RVO had the option for waypoint following through the WMI, or teleoperation via a gamepad controller. The following list identifies requests and feedback related to interaction with the RCV and specific use of controllers:

1) Users requested some individual configuration of controls. For example, the button layout of the gamepad for the RVO does not match current video game structures. There should be some customization to switch the gas and brake, or make the steering be controlled by the left analog stick.

2) Users indicated latency in joysticks while working in simulation, making it difficult to control, especially when shooting on the move. For interaction with the real vehicle, it was noted that most vehicle engagements would involve shooting on the move; users suggested that controllers needed to be more accurate during C2 vehicle motion.

3) Users also indicated that the gun slew rate was inconsistent with the sensitivity (i.e., goes from too slow to too fast).

4) It will be important to make gunner controls movable to other stations (e.g., in the event of casualty) rather than people having to get out of the vehicle.

Regarding concerns with joystick latency and engaging on the move, the RCV is intended to be deployed with the slew-to-cue functionality provided by ARES. The Warfighters were not able to use this functionality and thus had to use long sessions of teleoperation with the joysticks to acquire and engage targets—actions that will be mostly automated by ARES. There is a current technical issue with extended teleoperation that slows down the presentation. This has been seen on both the software-in-the-loop (SIL) and with the fielded system. Currently the engineering team is evaluating this issue. From a training perspective, the lack of ARES and other parts of the FCS will allow crews to utilize the system with failures to ensure they can handle issues with the technology and fight through those issues. In addition, future training will emphasize how to adapt the sensitivity of the slew rate during teleoperation for the RWS.

3. Conclusions

In review, the feedback provided by the Warfighters is invaluable and will be used as the basis for a variety of updates to the training, simulation testbed, software systems, and WMI stations. Above all, the involvement of Warfighters in this exercise provided the Wingman design teams with crucial data that reflect usage of the systems by experienced Warfighters as opposed to engineers or designers. The following updates have been made:

Training:

- Continue a combination of classroom (general instruction for the tasks, ranges, and team interactions), simulation (initial orientation to the WMI displays, controllers, and an opportunity to practice team communication), and live hands-on training (provided a more in-depth orientation to the team operations and the ability to practice).
- To support classroom learning, multimedia classroom aids are being developed to introduce the entire crew to the capabilities of the WMI, the DIDEA process, and a Table VI gunnery evaluation. This instruction will also include a more thorough introduction to the vehicles, weapon systems, and capabilities.
- To support simulation learning, specific "how-to" manuals with step-by-step instructions are being developed for each crew station. Training manuals will be updated to include more WMI features (e.g., widget placement options and individualization of the display; setting and updating BSOs).

- More directed live training with the actual vehicle with multiple targets and tasks will be conducted. Included will be the opportunity to experience and recover from potential errors.

SIL:

- Additional environments and target options to support multiple practice opportunities.
- New dynamic virtual environments to show Warfighters the potential use and capabilities of the Wingman vehicles beyond a gunnery range.

WMI:

- Testing will be done to identify the effects of cold weather (<55° F) on WMI functionality.
- Customization for sizing of sensor screen options are being explored.
- A visible scale on the map widget (aid in the judgment of distance) will be tested and included in training.
- Accuracy of range fan lengths on the map widget are being tested.
- Added functionality to toggle range fans on and off on the map widget is being explored.
- Additional features to customize phase lines with individual colors are in development.
- Default layouts for each crewstation with a shortcut feature are being developed.

RCV software and controllers:

- Testing and integration of the ARES system is underway and expected for use during the next event.
- Customization options for controllers are being explored.
- The slew rate is being tested to see if alternative options are needed to improve performance.

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Appendix. Scoring Matrix

Table A-1 Table IV performance scores per run

Step 1 Day 66	Step 2 Day 68	Step 3 Day 60	Step 4 Day 65	Step 5 Day 67	Step 6 Day 63	Step 7 Day 64	Table final score	Total Qual Eng	Run	Date
50	36	100	50	45	96	100	477	3	Dry run Marines	22 Oct
47	50	100	95	27	100	100	519	4	Dry run Soldiers	22 Oct
50	86	100	50	90	100	80	556	5	Demo live fire	23 Oct
DNF	DNF	80	47	DNF	100	79	306	3	Static live fire Soldiers	23 Oct
DNF	DNF	0	0	DNF	78	100	178	2	Static live fire Marines	23 Oct
93	0	100	50	100	100	100	543	5	Blank run Marines	24 Oct
87	85	100	99	84	100	100	655	7	Blank run Soldiers	24 Oct
50	5	100	93	68	100	100	516	4	Dry run Marines	24 Oct
98	96	100	97	81	100	100	672	7	Dry run Soldiers	24 Oct
36	84	100	90	91	100	100	601	6	Dry run Marines	24 Oct
96	90	100	100	97	100	100	683	7	Dry run Soldiers	24 Oct
94	89	0	98	98	100	100	579	6	Dry run Marines	25 Oct
97	89	100	99	92	100	100	677	7	Dry run Soldiers	25 Oct
50	47	0	50	0	80	100	327	2	Static live fire Marines	25 Oct
50	53	100	73	87	100	100	563	4	Static live fire Soldiers	25 Oct

Notes: Each run consisted of seven engagements (or steps). The maximum score possible per engagement was 100 points.
DNF = Did Not Fire.
Total Qual Eng means the total number of engagements out of seven on which a crew qualified on the Table VI gunnery evaluation.

Table A-2 Performance scores for dry runs

Step 1 Day 66	Step 2 Day 68	Step 3 Day 60	Step 4 Day 65	Step 5 Day 67	Step 6 Day 63	Step 7 Day 64	Table final score	Total Qual Eng	Run	Date
50	36	100	50	45	96	100	477	3	Dry run Marines	22 Oct
47	50	100	95	27	100	100	519	4	Dry run Soldiers	22 Oct
50	5	100	93	68	100	100	516	4	Dry run Marines	24 Oct
98	96	100	97	81	100	100	672	7	Dry run Soldiers	24 Oct
36	84	100	90	91	100	100	601	6	Dry run Marines	24 Oct
96	90	100	100	97	100	100	683	7	Dry run Soldiers	24 Oct
94	89	0	98	98	100	100	579	6	Dry run Marines	25 Oct
97	89	100	99	92	100	100	677	7	Dry run Soldiers	25 Oct

Notes: Each run consisted of seven engagements (or steps). The maximum score possible per engagement was 100 points.
Total Qual Eng means the total number of engagements out of seven on which a crew qualified on the Table VI gunnery evaluation.

Table A-3 Performance scores for blank runs

Step 1 Day 66	Step 2 Day 68	Step 3 Day 60	Step 4 Day 65	Step 5 Day 67	Step 6 Day 63	Step 7 Day 64	Table final score	Total Qual Eng	Run	Date
93	0	100	50	100	100	100	543	5	Blank run Marines	24 Oct
87	85	100	99	84	100	100	655	7	Blank run Soldiers	24 Oct

Notes: Each run consisted of seven engagements (or steps). The maximum score possible per engagement was 100 points.
Total Qual Eng means the total number of engagements out of seven on which a crew qualified on the Table VI gunnery evaluation.

Table A-4 Performance scores for stationary live-fire runs

Step 1 Day 66	Step 2 Day 68	Step 3 Day 60	Step 4 Day 65	Step 5 Day 67	Step 6 Day 63	Step 7 Day 64	Table final score	Total Qual Eng	Run	Date
DNF	DNF	80	47	DNF	100	79	306	3	Static Live-Fire Soldiers	23 Oct
DNF	DNF	0	0	DNF	78	100	178	2	Static Live-Fire Marines	23 Oct
50	47	0	50	0	80	100	327	2	Static Live-Fire Marines	25 Oct
50	53	100	73	87	100	100	563	4	Static Live-Fire Soldiers	25 Oct

Notes: Each run consisted of seven engagements (or steps). The maximum score possible per engagement was 100 points.
DNF = Did Not Fire.
Total Qual Eng means the total number of engagements out of seven on which a crew qualified on the Table VI gunnery evaluation.

List of Symbols, Abbreviations, and Acronyms

ARES	Autonomous Remote Engagement System
BSO	battle space object
C2	Command and Control
CCDC	Combat Capabilities Development Command
CSTS	Combat Skills Training School
DIDEA	Detect, Identify, Decide, Engage, and Assess
FCS	fire control system
LRAS3	long-range advanced scout surveillance system
JCTD	Joint Capabilities Technology Demonstration
MUM-T	manned–unmanned teaming
PLWRWS	Picatinny Lightweight Remote Weapon System
RCV	???
RTK	Robotic Technology Kernel
RVG	robotic vehicle gunner
RVO	robotic vehicle operator
RWS	remote weapon station
SA	situation awareness
SIL	software-in-the-loop
TC	training circular
TTPs	tactics, techniques, and procedures
VC	vehicle commander
WMI	Warfighter Machine Interface

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