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US ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 2-2-542
DTIC AD No.

8 July 2008

Safe Operation of Weaponized Unmanned Ground Vehicle (UGV) Systems

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1. SCOPE.

The procedures in this Test Operating Procedure (TOP) describe methods for testing performance and safety of lethal or non-lethal weaponized Unmanned Ground Vehicles (UGVs). The basics for UGV testing are outlined in TOP 2-2-540^{1*}. The basics for testing weapon systems are outlined in several procedures listed in the references section of this document; this document focuses on the unique aspects of testing weaponized vehicles that operate via remote teleoperation.

2. FACILITIES AND INSTRUMENTATION.2.1 Facilities.

<u>Item</u>	<u>Requirement</u>
Open test areas as defined in cited TOPs.	As required
Lab for Radio Frequency (RF) hardwiring the OCU and vehicle.	As required

2.2 Instrumentation.

<u>Devices for Measuring</u>	<u>Permissible Measurement Uncertainty</u>
RF resolution bandwidth	± 15 kHz
RF transmitted and received power	$\pm .1\%$ of value
RF attenuation	± 1 db
Acceleration	$\pm 5\%$ of reading or .1g (whichever is greater).
Video and audio of remote operator actions and comments	30 frames per second
Weapon firing signal detector and indicator	0.1% of voltage or current needed to fire the weapon.

3. REQUIRED TEST CONDITIONS.

a. UGV and independent emergency shutdown system operators must meet training requirements for test article operation, test area familiarization, and local SOPs.

b. Software testing defined in TOP 2-2-540 must be sufficiently complete in regard to mobility and weapon system operation.

* Superscript numbers correspond to those in Appendix C, References

c. The test article must comply with the safety and instrumentation requirements defined in TOP 2-2-540. In particular:

(1) For any weaponized UGV capable of injuring or killing a person at any range, an independent emergency shutdown system must be properly installed and its functionality must be verified prior to any other testing or training activities.

(2) Weaponized UGVs must be instrumented to support the critical information analysis and displays as needed by the test director to support test control and monitoring.

(3) Each weaponized UGV shall be physically and electrically restrained from vehicular and turret motion until sufficient environmental, subsystem, software, data link, mobility, and integrated vehicle-weapons related testing has provided sufficient confidence to allow for mobile operation of the weaponized UGV on a test range.

(4) Firing signal detectors and indicators must be installed in place of projectiles for each weapon aboard the UGV. Once sufficient confidence has been established, a weaponized UGV with live projectiles can operate in test areas.

(5) A weaponized UGV configured in a manner that could fire or launch anything that could injure a person at any range to include training rounds shall be marked with unique flags or lights to indicate the presence of the hazard. A UGV configured in a manner that renders it physically and electrically unable to fire or launch anything that could injure a person shall have unique flags or lights to indicate the lack of a firing hazard. At all times during testing or training, the UGV shall be equipped with the appropriate flags or lights. This requirement alerts all personnel to the most hazardous state of the vehicle during a test event.

(6) Unique warning lights that warn nearby personnel of vehicle movement must be installed.

d. Safe limits of UGV mobility as described in TOP 2-2-541² must be understood before initiating weapons-related testing for UGVs.

e. The safety areas for each weapon type carried on the vehicle in each firing mode must be established in forward, lateral, and rearward directions as needed to keep personnel and equipment safe. Additional safety areas must also be established based on where the vehicle could go during uncommanded steering and full throttle acceleration before the vehicle can be brought to a controlled stop in a safe condition. Use TOP 3-2-813³ in planning for direct fire weapons such as guns and rockets. Obtain missile cold launch and fly out information when determining safety fans for missiles such as Javelin. Be aware that some missiles have a significant vertical component to their flight trajectories in some attack modes, which is particularly important when planning and conducting tests in urban environments.

f. Regions where the data links are anticipated to become marginal for either the UGV, weapons control data link, or the emergency shutdown system must be identified before the start of testing. This is especially critical near hills and forested areas where RF signal attenuation is higher.

g. Weapon safety requirements for the specific type of munitions aboard a UGV, such as personnel exposure limits and display of explosive hazard placards, shall be identified and followed.

h. Test results of individual weapons and associated fire control systems installed on a UGV must be reviewed prior to weaponized UGV testing.

i. Vehicle blind spots overlaid on weapon hazard zones (e.g.: firing zone, launch debris zone, etc.) must be available.

j. Identification, descriptions, and interfaces for all forms of weapon control systems such as an Operator Control Unit (OCU) and a Remote Firing Control System (RFCS). An RFCS is a term that broadly encompasses weapon control systems that are totally independent of UGV control systems other than possibly sharing a common power source.

4. TEST PROCEDURES.

4.1 Teleoperated Weapon Control Tests.

4.1.1 OCU Field of Vision. This test characterizes the extent to which the remote operator can observe the battlefield.

a. Conduct procedures outlined in TOP 3-2-812⁴ using the method for combat vehicles. Capture data from each extreme in sensor zoom from each sensor that could be used during weapons employment.

b. Record FOV measurements of what can be observed through the OCU.

c. Record observations on operator actions required to suitably maintain battlefield awareness during weapon system operation.

d. Conduct analysis to determine how much of the battlefield the remote operator can see using weapon-related imagery.

4.1.2 OCU Visibility of Field of Fire (FOF). This procedure compares OCU visibility of the battlefield with FOF to determine conditions that may lead to poor visibility of an area that will be fired upon.

- a. Conduct the procedures as defined in TOP 3-2-813.
- b. Conduct the procedures as defined in OCU FOV test.
- c. Compare field of fire to available OCU FOV.

4.1.3 Demonstrated Controller Functions and Indications. This test demonstrates weapon-related control functions and the suitability of weapon status indications available both when approaching the UGV and on control units.

- a. During this procedure, note any weapon system anomalies or any issues related to timeliness and accuracy of status reporting.
- b. Ensure all lethal and non-lethal projectiles are removed from the weapon.
- c. Load weapon with firing signal detector.
- d. Exercise all weapon-related functions associated with unlocking, slewing, tracking, locating, designating, arming, and firing the weapon using each control unit.
 - (1) Note: Attempt to fire weapon when loaded only with firing signal detector.
 - (2) Record weapon functions available with each control unit.
 - (3) Record indications of weapon status for each control unit.
 - (4) Record visual cues associated with each weapon status available when approaching the vehicle.
- e. Exercise all weapon-related functions associated with safing the weapon for transportation and handling using each control unit.
 - (1) Record weapon functions available with each control unit.
 - (2) Record indications of weapon status for each control unit.
 - (3) Record visual cues associated with each weapon status available when approaching the vehicle.
- f. Determine the overall suitability of available visual weapon status indications when approaching the vehicle and on control units.

4.1.4 Demonstrated Controller Order of Precedence. Given that some weaponized UGVs have multiple controllers, this test determines the order of precedence relative to weapon system operation.

a. Tethered controller override.

(1) Plug in tethered controller. This type of controller is typically used when operating a UGV in facilities, during some maintenance activities, or during periods of high RF interference out in the field. It is a hand held device that plugs directly into the UGV and requires the operator to walk with the vehicle during vehicle motion.

(2) While the tethered controller is operational and in control of the vehicle, attempt to take control of the weapon using both the OCU and the RFCS. Document observations.

b. OCU override.

(1) Connect to the UGV via OCU. This controller is usually the primary means of operating the UGV during a mission.

(2) While the OCU is operational and in control of the vehicle, attempt to take control of the weapon using both the tethered controller and the RFCS. Document observations.

c. RFCS override.

(1) Connect to the UGV via RFCS. This is a weapon control system that is independent of a UGV control system and is used exclusively to operate the weapon system. However, integration into a UGV system could inadvertently disrupt controllability of the UGV.

(2) While the RFCS is operational and in control of the weapon, attempt to take control of the weapon using both the tethered controller and the OCU. Document observations.

d. Analyze results to identify the inherent order of precedence among controllers.

4.2 Teleoperated Weapon Data Link Tests. The following subtests may be performed concurrently. Ensure that the weaponized UGV is fully restrained and/or confined for these subtests.

4.2.1 Data Link Degradation Effect Procedures. This test identifies characteristics of system degraded data link operation.

a. Ensure all lethal and non-lethal projectiles are removed from the weapon.

b. Load weapon with firing signal detector. This will be used to identify uncommanded weapon firing.

- c. In a laboratory setting, hardwire the OCU and the vehicle together with variable attenuators between them set for a low degree of attenuation.
- d. Operate the vehicle in a restrained or confined area within the facility according to a predefined set of actions.
- e. As affects become apparent, record the attenuation setting and collect data and observations on the effects on both weapon and vehicle operation and OCU imagery.
- f. Upon completion of predefined actions increase the attenuation by a designated amount (e.g. 10dB) and repeat vehicle operation. Continue until data link is lost.
- g. Repeat for RFCS and emergency shut down systems.
- h. Analyze results to determine trends associated with the effects of increasing data link degradation on UGV weapon system operation.

4.2.2 Weapon Lost Link Behavior. This test builds an understanding of how armed weapons behave when the link to the control unit (tethered controller, OCU, RFCS) is lost.

- a. Ensure all lethal and non-lethal projectiles are removed from the weapon.
- b. Load weapon with firing signal detector.
- c. Perform the following for each available control unit (tethered controller, OCU, RFCS):
 - (1) Establish weapon control using the control unit, and arm the weapon with the weapon loaded only with firing signal detector.
 - (2) Disconnect the control unit. This may be achieved by unplugging the device or by adjusting a hardwired variable attenuator to infinity (for RF systems).
 - (3) Immediately record any observable changes in weapon state.
 - (4) Wait 3 minutes or until the UGV and/or weapon is programmed to change state.
 - (5) Record any observable changes in weapon state and the elapsed time from when link was lost.
 - (6) Reestablish control using the same controller.
 - (7) Record indications of weapon state both visually and as indicated on the control unit.

d. Review results to identify behavior of the weapon system when data link is lost and when it is reacquired.

4.3 Teleoperated Weapon Operation.

4.3.1 Teleoperated Weapon Performance. The purpose of this test is to identify the effects of teleoperation on weapon fire control.

a. Perform appropriate system level tests from ITOP 3-2-836⁵ Section 2, and as noted in TOP 2-2-540, Section 6.

b. Record observations of the effects of the data link, control unit functions and displays, and human-machine interfaces on weapon controllability and accuracy.

4.3.2 Firing Affects on Teleoperation. The purpose of this test is to examine how factors such as vibration and debris from weapon firing affect the remote operator's ability to observe the target and target area via teleoperation.

a. Emplace the UGV and fixed targets.

b. Fire one round.

c. Record the amount of time during which the remote operator cannot see the target or target area enough to discern key objects of interest.

d. Describe the affects that restrict remote operator viewing of the target or target area to include launch debris, smoke, shock, and vibration.

e. Fire multiple rounds. Record restrictions to viewing the target and target area as before.

f. Perform for each weapon selectable.

g. Perform for each available target viewing sensor and sensor setting combination.

h. Perform for each state of the automatic target tracker (if so equipped).

i. Repeat for moving vehicle/stationary target as appropriate to intended mission.

j. Repeat for moving vehicle/moving target as appropriate to intended mission.

k. Review results to determine the overall firing effects on safe teleoperation of the weapon.

4.4 Environmental Operating Tests. This test identifies effects of a variety of operating environments on weaponized teleoperated UGVs.

a. Conduct climatic and electromagnetic tests as defined in TOP 2-2-540 and system requirements documents. While chamber testing offers a valuable initial look at system performance, open air climatic testing should be considered to examine the synergistic effects of the environment imposed on the system to include changes in mechanism response times, component thermal stresses, and vehicle shock and vibration due to variations in suspension stiffness and terrain hardness. Increased OCU image motion due to changes in vehicle motion, OCU image response delays, and OCU image contrast variations due to temperature extremes can combine in a manner that severely degrades the performance and safe operation of weaponized UGVs at temperature extremes.

b. Perform system level functionality tests before, during, and after exposure to environments.

c. Record effects on the control units, vehicle, or data link that interfere with weapon operation or employment.

4.5 System Anomaly Tests. This procedure outlines activities required to identify and track weaponized UGV anomalies.

a. Record each occurrence of uncommanded or unresponsive actions or status change that occurs at any time during the test program.

b. Record operator actions leading up each incident.

c. Record each occurrence of weapon malfunction and associated indications. Note the type of control in use at the time of the incident.

5. DATA REQUIRED.

5.1 Teleoperated Weapon Control Test Data Requirements.

5.1.1 OCU Field of Vision.

a. Data as defined in TOP 3-2-812.

b. Observations on operator actions required to observe the battlefield relative to weapon operation.

c. OCU settings relative to field of view.

5.1.2 OCU Visibility of Field of Fire.

- a. Results from TOP 3-2-813.
- b. Results from OCU Field of View test.

5.1.3 Demonstrated Controller Functions and Indications.

- a. List of demonstrated weapon status indications available for each control unit (tethered controller, OCU, RFCS).
- b. List of demonstrated weapon functions controllable by each control unit.
- c. List of visual indications of weapon status.
- d. Observations on timeliness and accuracy of reported indications.

5.1.4 Demonstrated Controller Order of Precedence.

- a. Observations of the ability of one controller to take over another.
- b. When plugged in, the tethered controller takes control of the weapon from OCU.
(Y/N)
- c. When connected by RF data link, the OCU takes control from the tethered controller.
(Y/N)
- d. When plugged in, the tethered controller takes control of the weapon from RFCS.
(Y/N)
- e. When connect by RF data link, the RFCS takes control from the tethered controller.
(Y/N)

5.2 Teleoperated Weapon Data Link Test Data Requirements.

5.2.1 Data Link Degradation Effects.

- a. List of observed data link effects on weapon responsiveness.
- b. Effects on OCU Imagery.
 - (1) Description of OCU imagery effects relative to weapon operation due to data link degradation.
 - (2) Screen captures or video captures of OCU imagery showing various stages of imagery degradation.

- c. List of indicators of Emergency Shutdown System degradation.
- d. Order of data link degradation and failure.
 - (1) Order in which data links significantly degraded system capabilities.
 - (2) Order in which data link fail completely.
 - (3) List of attenuation settings with related observations.
 - (4) Description of operating environment (open flat terrain, urban terrain, etc.) relative to observations and effects.

5.2.2 Weapon Lost Link Behavior.

- a. Indications of weapon state before and after time out period on each control unit (tethered controller, OCU, RFCS).
- b. Indications of weapon state after control is regained on each control unit (tethered controller, OCU, RFCS).
- c. Observations of weapon status behavior before, during, and after control unit loss of control.

5.3 Teleoperated Weapon Operation Test Data Requirements.

5.3.1 Teleoperated Weapon Performance Tests.

- a. Results from ITOP 3-2-836 testing.
- b. Observations of teleoperated effects on weapon performance and employment.

5.3.2 Firing Affects on Teleoperation.

- a. Number of rounds fired (ea).
- b. Accelerations of vehicle chassis and weapon cameras (g^2/hz).
- c. Video Impairment during Weapons Fire.
 - (1) Time remote operator's view is obscured by firing/launching debris (sec).
 - (2) Time remote operator's view is obscured by motion or vibration of remote viewing sensor (sec).
 - (3) Firing debris prevents operator from knowing where the round hits. (Y/N)

(4) Motion/vibration of remote view sensor prevents operator from knowing where the round hits. (Y/N)

d. Supplemental Information.

(1) Sensors used in teleoperated weapon operation.

(2) Sensor selection (type).

(3) Sensor settings (FOV, contrast, etc.).

(4) Automatic target tracker state (on/off).

5.4 Environmental Operating Condition Test Data Requirements.

a. List of environments to which the system was subjected, alone or in combination.

b. Data requirements as defined in environmental test standards.

c. Observed effects on control units to include menu responsiveness, control freedom of movement, screen resolution, brightness, and contrast.

d. Observed effects on weapon responsiveness and functionality.

e. Results of system level functionality tests.

5.5 System Anomaly Data Requirements.

a. Type of incident (uncommanded or unresponsive action or status change, weapon malfunction).

b. Time & location of incident.

c. Environmental conditions in which incident occurred.

d. Vehicle and weapons states at the time of the incident.

e. Firing indicator status before and after incident.

f. List of known systems or devices operating nearby.

g. Sequence of operator actions leading up to the incident.

6. PRESENTATION OF DATA.

6.1 Teleoperated Weapon Control Results.

6.1.1 OCU Field of Vision.

a. Provide a table indicating max and min fields of view for sensors capable of being used during weapons employment.

b. Describe limitation that the remote operator experiences in viewing the battlefield relative to teleoperating the weapon system.

6.1.2 OCU Visibility of Field of Fire.

a. Graphically display the relationship between field of fire for each weapon and OCU Field of View Results.

b. Identify limitations on safe operation due to insufficient fields of view.

6.1.3 Demonstrated Controller Functions and Indications.

a. Table of demonstrated weapon state indications available for each control unit (tethered controller, OCU, RFCS).

b. Table of demonstrated functions available for each control unit (tethered controller, OCU, RFCS).

c. Table of weapon status indications available when approaching the vehicle.

d. Observations on timeliness and accuracy of reported indications.

6.1.4 Demonstrated Controller Order of Precedence.

a. Describe order of precedence between tethered controller, OCU, and RFCS weapon control systems.

b. Describe demonstrated interlocks available to prevent OCU or RFCS from controlling weapon system while under tethered control.

6.2 Teleoperated Weapon Data Link Results.

6.2.1 Data Link Degradation Effects.

a. Describe the observed effects of data link degradation and their effects on weapon system responsiveness and controllability.

- b. Describe how changes in OCU imagery affect ability to remotely operate the weapons safely. Include screen captures and associated conditions as needed.
- c. Describe indicators of data link degradation on the emergency shutdown system.
- d. Describe the relative order in which critical data links (OCU, RFCS, emergency shutdown system) experience significant degradation and failure.

6.2.2 Weapon Lost Link Behavior.

- a. Present a table comparing weapon states immediately after loss of control, after weapon timeout, and then when control is regained for each control unit (tethered controller, OCU, RFCS).
- b. Briefly describe weapon status behavior immediately after link to the control unit is broken.
- c. Briefly describe weapon status behavior when a control unit is reconnected.
- d. Identify the demonstrated timeout period, after which the weapon reverts to a safe state. Describe the safe state to which the weapon reverts after weapon timeout.

6.3 Teleoperated Weapon Operation Results.

6.3.1 Teleoperated Weapon Performance Tests.

Present observations of teleoperated effects on weapon performance and employment.

6.3.2 Firing Affects on Teleoperation.

- a. Describe firing affects on the ability of a remote operator to observe target or impact area when firing single and multiple rounds.

6.4 Environmental Operating Condition Results.

- a. Provide a table of environments to which the system was subjected either alone or in combination.
- b. Describe the environmental effects on control unit displays and controls.
- c. Describe the environmental effects on weapon responsiveness and controllability.
- d. Summarize the overall effects of these environments on weapon operation and employment.

6.5 System Anomaly Results.

- a. Present a table that summarizes uncommanded or unresponsive vehicle and weapon incidents. Highlight firing indications or vehicle movements at the time of the anomaly.
- b. Present a table that summarizes operator actions that resulted in unintended vehicle or weapon operation.
- c. Present a table of weapon malfunctions and associated indications at each controller and when approaching the vehicle.

APPENDIX A. GLOSSARY

Term	Definition
Firing Signal Detector.	A non-explosive device installed in a weapon in place of the projectile intended to provide an indication of when a firing signal was delivered to the weapon in a manner that is safe to personnel next to the system.
Operator Control Unit (OCU)	The remote work station for the human operator that enables remote control of selected driving and associated functions.
Remote Firing Control System (RFCS).	A type of system that broadly encompasses weapon control systems that are totally independent of UGV control systems.
Tethered Controller	A hand held controller that plugs directly into a UGV; typically used during maintenance operations or when maneuvering the UGV within a facility.

APPENDIX B. ABBREVIATIONS.

EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FOV	Field of View
ITOP	International Test Operations Procedure
MOUT	Military Operations in Urban Terrain
OCU	Operator Control Unit
RF	Radio Frequency
RFCS	Remote Firing Control System
TOP	Test Operations Procedure
UGV	Unmanned Ground Vehicle

APPENDIX C. REFERENCES.

1. TOP 2-2-540, Testing Of Unmanned Ground Vehicle (UGV) Systems, 30 June 2008.
2. TOP 2-2-541, Safe Operation of Mobile Unmanned Ground Vehicle (UGV) Systems, 8 July 2008
3. TOP 3-2-813, Field of Fire, 22 March 1985.
4. TOP 3-2-812, Field of Vision, 23 Feb 1966.
5. ITOP 3-2-836(0), Combat Vehicle Fire Control Systems Overview Document, 16 October 2000.

For information only (related publications).

- a. Unmanned Systems Safety Guide for DoD Acquisition, First Edition, (Version .96), Jan 2007.
- b. A Semi-Autonomous Weapon Payload, Kogut, SPIE 2005.

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