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14. ABSTRACT
This document describes the procedures for determining the mobility related capabilities and characteristics of UGVs. It focuses heavily on the contribution of teleoperation to overall mobility and safe operation.

15. SUBJECT TERMS

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US ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 02-2-541 13 July 2010
DTIC AD No.

Safe Operation of Mobile Unmanned Ground Vehicle (UGV) Systems

*This TOP supersedes TOP 02-2-541, dated 08 July 2008.

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1. SCOPE.

a. This document describes the procedures for determining the mobility capabilities and characteristics of remotely and teleoperationally controlled Unmanned Ground Vehicle (UGVs). It focuses on the contribution of teleoperation to overall mobility and safe operation. This TOP does not address the operation of autonomously controlled vehicles.

b. These procedures are intended to build upon the mobility related Test Operating Procedures (TOPs) called out in TOP 02-2-540[1]** and to set the stage for testing autonomous mobility capabilities and characteristics. Tests of lethal and non-lethal weaponized UGVs must refer to TOP 02-2-542[2].

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
Enclosed facility	Vehicle lab testing
Variable attenuators	± .5 dB
Areas with intersecting roads and narrow alleys	

2.2 Instrumentation.

Devices for Measuring	Permissible Measurement Uncertainty
Radio Frequency Resolution Bandwidth	± 15 kHz
RF Transmitted And Received Power	± .1% of value
RF Attenuation	± 1dB
OCU Position	± 0.5 m
Vehicle Position And OCU	± 0.5 m
Vehicle Speed	± .4 km/hr
Vehicle Heading	$\pm 1^{o}$
Pitch And Roll Rate	$\pm 100^{o}$/sec
Vehicle Computer Temperature	$\pm 1^{o}$ C
Vehicle Data Link Transceiver Temperature	$\pm 1^{o}$ C
Vehicle Power Bus Voltage	± 1 Volt
Time	± 0.1 sec
Independent Video Of Vehicle Movement	30 frames per second, Infrared (IR) or color (based on test conditions).
Acceleration	± 5% of reading or .1g (whichever is greater).

** Superscript numbers/letters correspond to those in Appendix B, References.

2.2.1 The selection of instrumentation and data collection equipment installed for UGV mobility testing should consider the following:

a. Equipment Mass Properties. The size and weight of the instrument and data recorders mounted on the test article must be small and light in comparison to the test article. The use of disproportionately large or heavy equipment may have an unacceptable effect on test results. Where feasible, weight should be removed to keep mass properties (center of gravity, weight, etc.) constant when an instrumentation package is added.

b. Real-Time Data Downloading. Wireless transmission of test data may interfere with normal system operation due to electromagnetic interference. Prior to test execution, compatibility between real-time data downlinks and system operation must be verified.

c. Spectrum Analyzers. This equipment is needed to identify the presence of other frequencies in use at any given time in the test, and should be operated in the vicinity of the UGV and the Operator Control Unit (OCU). Although systems are required to have a frequency authorization prior to the start of testing, establishing cause and effect during UGV mobility testing requires a means of ensuring that frequency interference is not a factor in test results.

d. UGV System Data Tap. A significant source of data in a test effort relative to UGV mobility will come from UGV system data taps, especially for advanced autonomous capabilities. This information is useful for establishing cause and effect when examining test results, as well as for monitoring the test article to ensure safety on the test range. System data taps and supporting data harvesting and analysis tools must be compliant with the data bus standards of the test article. Many emerging UGV systems are compliant with the Joint Architecture for Unmanned Systems (JAUS) standard. The Joint Ground Robotics Enterprise (JGRE), formerly known as the Joint Robotics Program, established JAUS as a standard architecture for UGVs developed within the JGRE.

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 must be sufficiently completed as defined in TOP 02-2-540, and must be completed in accordance with DTC Policy Bulletin No. 1-09[3], Software Safety Verification Policy and Guidelines, 29 July 09.

c. The test article must comply with the safety and instrumentation requirements defined in TOP 02-2-540, including the following:

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

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

(3) Unique warning lights that warn nearby personnel of vehicle movement must be installed. It must be verified that operation of these lights does not interfere in any way (physically or electronically) with the system under test (SUT).

(4) Lift and Tie-down procedures, as well as procedures for loading the SUT onto a transport vehicle must be finalized prior to the start of testing.

d. Standoff distances from the UGV must be established for personnel and equipment in forward, lateral, and rearward directions. Standoffs must consider where the vehicle could go during uncommanded movement and full throttle acceleration.

4. TEST PROCEDURES.

4.1 Vehicle Subsystem Tests.

These tests identify key operating characteristics associated with UGV subsystems. Completing these tests first in a UGV test program are part of an overall strategy to slowly build confidence in UGV system robustness and to prepare the tester for additional phases of testing.

4.1.1 Tethered Controller Test.

This test identifies the operating characteristics of UGVs while under control of a hand-held controller that plugs directly into the vehicle. Such a device is typically used for vehicle movement within maintenance facilities, for loading or unloading the vehicle from a trailer, or anytime vehicle movement on a test range cannot be performed via RF data link. It also tests for lockouts that prevent other controllers from taking control of the vehicle. For this phase of testing, the system should be exercised with the vehicle tracks/wheels suspended above ground (e.g., on jack stands) before performing full-function checks with the unrestrained vehicle.

a. Ensure the OCU is powered off.

b. Perform the Vehicle Fine Control subtest (paragraph 4.4.3) using the tethered controller.

c. Power up the OCU and look for indications that the tethered controller has control of the vehicle.

d. Use the OCU to attempt to take control of the vehicle. Record indications of controlling the unit before and after the OCU control attempt.

e. Disconnect the tethered controller and allow OCU to take control of the vehicle.

f. Plug tethered controller back into the vehicle and attempt to control vehicle. Record observations that indicate the tethered controller now controls the vehicle.

4.1.2 System Field of View Test.

This test identifies regions around the vehicle that cannot be seen by the remote operator via teleoperation, and identifies the effort required to detect people or impairments to mobility near the vehicle.

a. Use the procedures outlined in TOP 03-2-812[4] to obtain a field of vision of sensors as presented through the OCU. Be sure to address each extreme in sensor pan, tilt, and field of view (FOV) setting. Measure the FOV of each sensor at each range setting.

b. Record the list of operator actions and timelines required to use one sensor to observe a blind spot of another sensor.

c. Using collected data identify residual blind spots. Residual blind spots are areas that cannot be observed by switching between views or by combining views.

d. Determine the size and location of residual blind spots. Address the likelihood that people or objects large enough to pose safety risks or impair mobility could fit within residual blind spots.

4.1.3 Vehicle State Reporting Test.

This test is used to identify variations between the reported and actual vehicle states. Accurate state reporting is essential for ensuring that the vehicle is safe enough to approach and handle and for performing certain tasks according to the intended mission.

a. Identify key vehicle data reported to the OCU. States needed for safe operation during mission execution include position, speed, heading, steering, pitch and roll attitude, and reporting sensor viewing angles. States needed to ensure that the vehicle is safe to approach include gear and brake settings, engine power level, vehicle electrical power state, and the states of any articulating parts (e.g.: turrets, arms, etc.).

b. Record both the OCU reported vehicle data and the vehicle truth data. Obtain truth data from test instrumentation independent of the system and from visual observation of the system.

c. Identify variations between reported and actual states that may affect safe vehicle operation.

4.2 Emergency Shutdown Test.

This test provides confidence to the testers that the emergency shutdown system can be relied upon to shut the UGV down in a manner that enables it to be safely approached. This subtest is intended for both RF and panic stop button shutdown systems. Of particular importance is the testing of independent emergency shutdown systems that may be applied to some systems. Conduct in conjunction with the Data Link Degradation Effects subtest (paragraph 4.3) with the following additions:

a. Identify each available means of shutting down a vehicle in an emergency on a test range should the vehicle become uncontrollable. These may include test center applied independent kill systems, prime item developer independent kill systems, or any other system that is not intended to be a part of the UGV system and that does not use the system's data link.

b. Restrain or confine the vehicle, then power it up and establish a slow wide turn. Wheels or tracks should be turning as the vehicle is steered to negotiate a large radius turn.

c. Use an emergency shutdown system to shut down the vehicle. Record the results of each shutdown.

d. Repeat for each means of shutting down the system in an emergency.

4.3 Data Link Degradation Effects.

This test identifies the effects of data link degradation on overall system performance and operating characteristics.

a. In a laboratory setting, hardwire the OCU and the vehicle together with variable attenuators between them with a low initial attenuation setting.

b. Using mission planning software on the system, enter the time period the UGV is to wait before executing lost link procedures. If available, select a lost link behavior with discernable changes in vehicle function (e.g.: hard turn, back up, etc.).

c. Operate the vehicle in a restrained or confined area within the facility according to a defined set of planned functions. Include maneuvers that challenge obstacle negotiation and collision avoidance with degraded and/or delayed imagery.

d. Incrementally increase the attenuation by a consistent amount and repeat vehicle operation.

e. As affects become apparent record the attenuation setting and observations on the effects of data link degradation on both vehicle operation and OCU imagery. Record evidence of degradation effects.

f. Continue until data link is lost.

g. Record observations on UGV actions and OCU indications when data link is lost.

h. Allow vehicle to remain in lost link state for 3 minutes or 20% longer than what was programmed for lost link procedures, whichever is longer. This allows time for any undocumented vehicle behaviors to become apparent.

i. Decrease attenuation by half the amount by which it was being increased and wait 30 seconds for data link reacquisition to occur. Repeat this step until link is reestablished.

j. Record observations on UGV actions and OCU indications when data link is restored.

4.4 Automotive Performance.

These tests identify overall system performance under each mode of control.

4.4.1 Tailored Automotive Tests.

Conduct automotive tests as defined in TOP 02-2-540. For each of the following subtests include the following information as appropriate to intended mission:

a. Grades and Slopes. Record the information made available to the remote operator regarding slope angle and impending vehicle roll over. Record remote operator indications of nose slide or tail slide. Conduct for each mode of control.

b. Standard Obstacles. For each mode of control, maneuver the vehicle into position and conduct one trial of negotiating the standard obstacles. Record observations on OCU control inputs required for steering effort. Record issues associated with maneuvering the vehicle up to or over the obstacles.

c. Fording. Identify effects of water near or on driving sensors to include degradation of imagery at the OCU. Record indications of loss of controllability or traction available to the remote operator. Record difficulties with water entry or exit associated with each mode of control.

d. Soft Soil Mobility. Record indications of loss of controllability or traction available to the remote operator.

e. Steering and Handling. For each mode of control, record steering and heading indications available to the remote operator. Record observations on suitability of the information available to the remote operator (steering and handling indications and the OCU fields of view) to support steering and handling related functions. Record observations on OCU control inputs required for steering effort.

f. Acceleration /Max Speed. Conduct for each mode of control. Record observations of OCU indications of vehicle speed and acceleration.

g. Braking. Conduct for each mode of control. Record observations of OCU indications of vehicle speed and braking effort.

4.4.2. Test for Driver Assist Functions.

Driver assist functions relieve the operator of certain burdens in operating the vehicle remotely or offer a degree of vehicle protection against operator actions that could inadvertently impair vehicle motion. They DO NOT relieve the remote operator of the fundamental task of driving the vehicle. Examples include speed control, heading control, and autonomous rollover avoidance to correct operator inputs that would otherwise cause a rollover.

a. During automotive tests described above, verify that known driver assist functions can be activated and deactivated as needed and that they function as intended.

b. Record OCU indications of the state of driver assist functions.

c. Record observations on system operation with driver assist function on and off.

d. Over the course of the overall test program record additional observations that may imply the presence of undocumented driver assist capabilities.

4.4.3 Vehicle Fine Control.

Although much of the conventional automotive testing examines the limits of automotive performance, this test is intended to examine the fine control inputs and responses needed for some situations. This test may be combined with the Tailored Automotive Tests (paragraph 4.4.1).

a. Acceleration.

(1) For each mode of control, instruct the remote operator to drive at set speeds using smooth transitions between each speed.

(2) Record observations on the system’s ability to finely adjust acceleration and speed.

(3) Measure the minimum UGV response that can be commanded by an OCU operator.

b. Braking.

(1) For each mode of control, instruct the remote operator to drive at set speeds using smooth transitions between each speed. Record observations on the system’s ability to finely reduce vehicle speed through braking.

(2) Identify a point in the distance and instruct the remote operator to stop the vehicle just in front of that spot. Record observations on the ability of the vehicle to be brought to a gentle stop at a designated point.

(3) Measure the minimum UGV response that can be commanded by an OCU operator.

c. Steering.

(1) For each mode of control, instruct the remote operator to move the vehicle through a figure eight course with road width no greater than 150% of overall vehicle width. Course must include at least one straight section. One turn should require a turn radius equal to the minimum demonstrated turn radius plus 25%.

(2) Operate the vehicle at approximately 10% of maximum demonstrated speed for two laps.

(3) Record observations on the ability of the vehicle to be kept within the lane. Record observations on the system's steering resolution.

(4) Measure the minimum UGV response that can be commanded by an OCU operator.

4.5 Teleoperation Effectiveness.

This test examines how well the overall operating characteristics of the UGV work together to support the soldier in employing a teleoperated UGV.

4.5.1 OCU Usefulness.

While many teleoperated systems have similar components and displays, huge variations may exist in the ease with which the UGV can be operated. This test examines the role of the OCU in enabling the remote operator to effectively use the UGV.

a. Observe remote operators and collect their comments throughout the test effort regarding usefulness of available controls and information to maneuver the vehicle as needed.

b. Obtain OCU video captures as needed to support remote operator comments.

4.5.2 Corner Negotiation.

This test is intended to identify UGV safe operating limitations due to difficulties the remote operator may have in seeing the area into which the vehicle is about to turn or in maneuvering the vehicle into a narrow area.

a. Beginning at off-road speed, slow the vehicle as needed to make turns onto intersecting roads. Two of the intersecting roads must be narrow: one road must be approximately 75% wider than the UGV, and one must be approximately 50% wider than the UGV. Turns must be made onto the narrow intersecting roads from both the left and the right. Turns must be conducted in both daytime and in nighttime conditions.

b. Conduct at least 3 trials of each condition.

c. Observe the remote operator's actions needed to clear the area before making the turn. Note the timelines associated with switching OCU displays between looking ahead of the vehicle and looking into the turn.

d. Collect comments from remote operators and independent observers on the suitability of teleoperation capabilities to safely turn the UGV.

4.5.3 Tracking and Steering Latency.

Test methodology remains under development for tracking, measuring, and analyzing how high-speed, teleoperated vehicles adhere to inputs from a remote driver or operator.

4.6 Environmental Operating Condition Tests.

These tests are intended to identify operating characteristics of teleoperated UGVs that result from exposure to extremes in environmental conditions.

a. Select environmental tests as defined in TOP 02-2-540 based on system requirements documents, intended missions, and mission locations.

b. Conduct Vehicle Fine Control (paragraph 4.4.3) and Teleoperation Effectiveness (paragraph 4.5) subtests, to the maximum extent possible, while exposed to required environmental conditions.

c. Record the environmental effects on overall system performance and safety. For key changes in system performance, specifically address the environmental effects that caused the performance reduction.

4.7 System Anomalies.

This section outlines additional information to be collected during the test program.

a. Early in the test effort, identify OCU indications of abnormal vehicle operation, and assess the safety status of the vehicle during each problem.

b. During each anomaly encountered in the test effort make note of the remote operator's ability to determine that a problem exists and to understand the nature of the problem.

c. Document all problems that involve the vehicle being in a state that is unsafe to approach.

d. Identify general recommended improvements to system documentation based on observed system capabilities and characteristics.

5. DATA REQUIRED.

5.1 Vehicle Subsystem Tests.

5.1.1 Tethered Controller Test Data.

a. Data from Vehicle Fine Control test.

b. List of indications at OCU that tethered controller has taken control of vehicle.

c. List of indications at OCU that OCU has taken control from tethered controller.

d. OCU can take and retain control of vehicle during tethered control. (Y/N)

e. Tethered controller can take and retain control while under OCU teleoperation control. (Y/N)

5.1.2 Vehicle Blind Spot Test Data.

a. Field of view (degrees horizontal, degrees vertical) for each setting of each sensor at each extreme in pan and tilt.

b. Azimuth and elevation boundaries of residual blind spots for areas that cannot be observed with any combination of sensors selectable at the OCU.

c. Size and locations of blind spots.

d. List of operator actions required to observe single sensor blind spots.

e. Time required to use one sensor to observe the blind spot of another sensor (sec).

(1) Sensor identification, pan and tilt setting, and FOV setting that has a blind spot.

(2) Sensor identification, pan and tilt setting, and FOV setting that is used to observe the blind spot.

f. Residual blind spot assessment:

(1) A person can fit in the residual blind spots while crouched. (Y/N)

(2) The residual blind spots can contain an object large enough to prevent vehicle motion. (Y/N)

(3) The remote operator can see enough via the OCU to maneuver the vehicle in confined areas. (Y/N)

5.1.3 Vehicle State Reporting Test Data (Reported and Truth).

a. Orientation and motion states:

(1) Heading (deg).

(2) Pitch and roll angles (deg).

(3) Speed (km/hr).

(4) Direction of travel (forward, reverse).

(5) Position.

b. Actuator commanded and reported states:

(1) Throttle (%).

(2) Braking (%).

(3) Steering (deg from centerline, direction of deflection).

(4) Gear (gear id).

(5) Vehicle electrical power.

(6) States of articulating parts (locked, unlocked, etc.).

(7) OCU sense feed states.

5.2 Emergency Shutdown Test Data.

List of indicators of Emergency Shutdown System degradation.

5.3 Data Link Degradation Effects.

a. Lost link mission plan settings.

b. Response and controllability data.

(1) Time command was issued by operator (sec).

(2) Time vehicle began to respond (sec).

c. Observed Effects.

(1) Screen captures or video captures of OCU imagery showing each stage of imagery degradation.

(2) List of attenuation settings and noted observations on OCU display quality and vehicle controllability.

(3) Observations on changes in system performance.

5.4 Automotive Performance.

5.4.1 Tailored Automotive Tests.

Supplemental data requirements for automotive performance TOPs include the following:

a. Grades and Slopes.

(1) Mode of control.

(2) OCU indications of slope angle, pitch and roll, and impending roll over.

(3) OCU indications of nose slide or tail slide.

(4) Observations on suitability of OCU displays for operation on slopes and grades.

b. Standard Obstacles.

(1) Mode of control.

(2) Time elapsed from first contact of vehicle with an obstacle to when the obstacle was completely passed (sec).

(3) List of extraordinary remote operator actions (actions other than those needed for normal vehicle operation) required to negotiate the obstacles.

(4) Observations of issues associated with maneuvering the vehicle up to or over obstacles.

c. Fording.

(1) Mode of control.

(2) List of effects of water near or on driving sensors to include degradation of imagery at the OCU.

(3) List of OCU indications of loss of traction.

(4) Observations on difficulties with water entry or exit.

d. Soft Soil Mobility.

(1) Mode of control.

(2) List of OCU indications of loss of traction.

e. Steering and Handling.

(1) Mode of control.

(2) List of OCU steering and heading indications.

(3) Observations on information available to the remote operator (steering and heading indication and OCU fields of view) to maneuver the vehicle.

f. Acceleration /Max Speed:

(1) Mode of control.

(2) Commanded speed.

(3) Achieved steady-state speed.

(4) Observations on the system's ability to finely adjust acceleration and speed.

g. Braking.

(1) Mode of control.

(2) Commanded speed.

(3) Achieved steady-state speed.

(4) Observations on the system's ability to finely adjust deceleration and speed.

(5) Description of marking used to identify the intended stopping location.

(6) Observations on the system's ability to brake to a designated spot.

5.4.2 Test for Driver Assist Capabilities.

a. Descriptions of observed driver assist capabilities.

b. Test conditions under which driver assist functions were observed.

c. OCU indications of driver assist status.

d. Remote operator can engage and disengage driver assist functions as needed. (Y/N)

e. Driver assist is only “on” with remote operator’s knowledge. (Y/N)

f. List of observed driver assist capabilities.

5.4.3 Vehicle Fine Control.

a. Max speed: meters per second.

b. Speed Resolution: Number of speed variations available, or “Continuously Variable” if a very high number.

c. Acceleration response: time to accelerate from zero to top speed (sec).

d. Decelerate response: time to slow to zero using only throttle control (sec).

e. Brake resolution: Able to incrementally adjust braking effort. (Y/N)

f. Brake response: distance covered when stopping from full speed to zero (m).

g. Steering resolution: Minimum steering input step size, or “Continuously Variable” if a very high number.

h. Steering response time: time required to go from straight ahead to full deflection in one direction. (sec)

i. Observations on ability of the remote operator to maintain specified courses, slow speeds, and to brake and accelerate gently.

j. The minimum UGV acceleration, steering, and braking response that can be commanded by an OCU operator.

5.5 Teleoperation Effectiveness.

5.5.1 OCU Usefulness.

a. Assessment of overall image quality, controls, and vehicle states to help the remote operator maneuver the vehicle around obstacles and through tight areas.

b. Description of the situations in which remote operator did not understand what was happening at the vehicle.

c. Screen captures or photos highlighting information supplied to remote operator while maneuvering the vehicle.

5.5.2 Corner Negotiation.

a. List of actions required for the remote operator to observe the area into which the vehicle is about to turn.

b. Observations on the success rate of completing turns into narrow paths.

c. Observations on the ability of the remote operator to look in one direction using vehicle sensors while the vehicle is moving in another.

d. Observations on the time and the care the remote operator has to put into making turns.

5.6 Environmental Operating Condition Test Data Requirements.

a. Data as defined in environmental TOPs and standards.

b. Data as defined in Vehicle Fine Control and Corner Negotiation subtests.

c. List of effects on OCU: menu responsiveness, control freedom of movement, screen resolution, brightness, contrast, and overall image quality for each sensor FOV and setting.

d. List of effects on the vehicle: vehicle responsiveness, vehicle fine control, and controllability.

e. Observations on ability of the OCU to be used to maneuver the vehicle safely and effectively.

f. Assessment of video display to support full vehicle mobility at required speeds during bright sunlight and in total darkness.

5.7 System Anomalies.

a. List of uncommanded or unresponsive situations.

(1) Occurrences of incorrect status reporting.

(2) Occurrences of uncommanded movement or state changes.

(3) Occurrences of violating safe boundaries in time or in space.

(4) Occurrences of abrupt system behaviors.

b. Observations regarding recurring anomalies (actions leading up to anomaly, environments, etc.).

c. Anomaly Resolution.

(1) Observations on sufficiency of information presented to the remote operator to identify anomalies.

(2) Observations on ability of the remote operator to remotely correct and resume mission.

(3) Data from vehicle data tap.

(4) Data from OCU data tap.

d. List of anomalies causing unsafe conditions.

e. Training and Documentation Improvements.

(1) Remote operator comments on system operation and mobility.

(2) List of discrepancies between actual vehicle operation and available documentation.

(3) List of inadvertent operator errors while maneuvering and controlling the vehicle.

6. PRESENTATION OF DATA.

6.1 Vehicle Subsystem Test Results.

6.1.1 Tethered Controller Test Results.

a. Present a table showing maximum automotive performance demonstrated during tethered controller operation for speed, steering, and braking.

b. Describe the automotive characteristics of the UGV under tethered control in context of vehicle operation in facilities. Describe control responsiveness and sensitivity to throttle, steering, and braking commands to enable both smooth changes for normal operation as well as abrupt changes needed to suddenly avoid a collision. Provide a recommendation for the number of people needed to act as safety observers while under tethered control to protect nearby personnel, facility equipment, and the test article.

c. Describe lockouts that prevent OCU control during tethered control as well as order of precedence available when a tethered controller is activated during OCU control.

d. Describe the suitability of the tethered controller for test support activities such as maneuvering the vehicle into and out of facilities, on and off ramps for transporting the vehicle, and getting the vehicle out of impaired mobility situations.

6.1.2 Vehicle Blind Spot Test Results.

a. Present side and top-down views of the UGV showing coverage of each sensor aboard the vehicle.

b. For systems that enable combined views or that enable the remote operator to shift between views, present one additional set of views (side and top-down) showing sensor coverage areas superimposed.

c. Describe the size of the residual blind spots that cannot be observed by switching or combining views that could contain a person (standing or crouched).

d. Describe the operator actions needed to detect people and impairments to mobility (e.g.: posts, trees) near the vehicle such as changing sensor selections or settings during system operation. Describe the consequences of those required actions on safe operation of the system around people, equipment, and facilities.

6.1.3 Vehicle State Reporting Test Results.

a. Describe the ability of the vehicle to promptly and accurately report its state to the OCU in the areas of: 1) Vehicle orientation and motion information such as heading, pitch and roll attitude, speed, and direction of travel; 2) commanded and reported automotive control settings for throttle, brake, steering, and gearing; and 3) driving sensor state information such as sensor selection, sensor field of view, sensor orientation settings such as pan and tilt, and sensor discrimination settings such as white-hot/black-hot.

b. Describe the suitability of reported information to safely operate the vehicle.

c. Describe the suitability of reported information to know when the vehicle is safe to approach.

6.2 Emergency Shutdown Test Results.

a. Describe indicators of data link degradation on each available emergency shutdown system.

b. Describe the overall effectiveness for each available emergency shutdown system. Describe the effects of emergency shutdown system activation on the vehicle along with the timeliness of each of those effects. Also, describe sufficiency of available indicators to the remote operator and to the independent shutdown system operator that the system is safe to approach and handle.

6.3 Data Link Degradation Effects.

a. Present a table or graph showing data link attenuation at each major change in system responsiveness or change in video quality sufficient to affect teleoperation of vehicle movement.

b. Describe the observed effects of data link degradation on system responsiveness and OCU imagery. Address changes in system response timeliness and the rate at which this degradation occurs (rapid, very gradually, etc.). Describe how changes in OCU imagery affect the ability of a remote operator to maneuver the vehicle safely. Include screen captures and associated conditions as needed to help describe the relationship between data link degradation and overall controllability and mobility of the system.

6.4 Automotive Performance.

6.4.1 Tailored Automotive Tests.

Present the results of each automotive test as required by each automotive TOP under each mode of control along with supplemental data defined in paragraph 5.4.1.

6.4.2 Test for Driver Assist Functions.

Describe any observed driver assist capabilities such as autonomous rollover avoidance actions, heading control, or speed control. Describe ability of remote operator to engage, disengage, and observe current state of any driver assist functions. Describe the observed functionality of each driver assist function.

6.4.3 Vehicle Fine Control.

Describe overall ability of the system to apply automotive capabilities in each mode of control. Include a narrative on the ability of the vehicle to be lined up properly to traverse obstacles in a timely manner, to be stopped at intended points, and to be turned at intended locations.

6.5 Teleoperation Effectiveness.

6.5.1 OCU Usefulness.

Describe the usefulness of vehicle controls, states, and imagery to support teleoperation.

6.5.2 Corner Negotiation.

Describe the remote operator's actions needed to clear the area into which the vehicle will make sharp turns. Describe the extent to which the operator can safely clear the area into which the vehicle will turn while ensuring the area is clear ahead of the vehicle. Describe safety implications of demonstrated corner negotiation capabilities and limitations.

6.6 Environmental Operating Condition Testing.

a. Describe the environmental effects on Vehicle Fine Control and Teleoperation Effectiveness.

b. Describe the environmental effects on OCU controls. Describe the effects on display responsiveness, brightness, contrast, and resolution.

c. Describe the environmental effects on vehicle responsiveness and controllability.

d. Describe the environmental effects on data link performance.

e. Summarize the overall environmental effects on system performance and safety.

6.7 System Anomalies.

a. Present a table summarizing uncommanded activities and unresponsive situations with associated conditions.

b. Clarify or highlight specific abnormalities as needed and cite TIRS, video clips, or other sources if useful.

c. Describe the sufficiency of information available to the operator to remotely identify and correct anomalies and continue with a task. Identify anomalies that the system can correct on its own (i.e.: do not involve remote operator actions) and enable task continuation without reprogramming or re-initialization.

d. List the anomalies that leave the vehicle in an unsafe state to approach and require subsequent activation of the emergency shutdown system.

e. Describe the areas where training or documentation needs emphasis to ensure safe operation of the system.

f. Provide simple recommendations for system improvement.

6.8. Test Data Examples.

6.8.1 Vehicle Blind Spot Test Data Example.

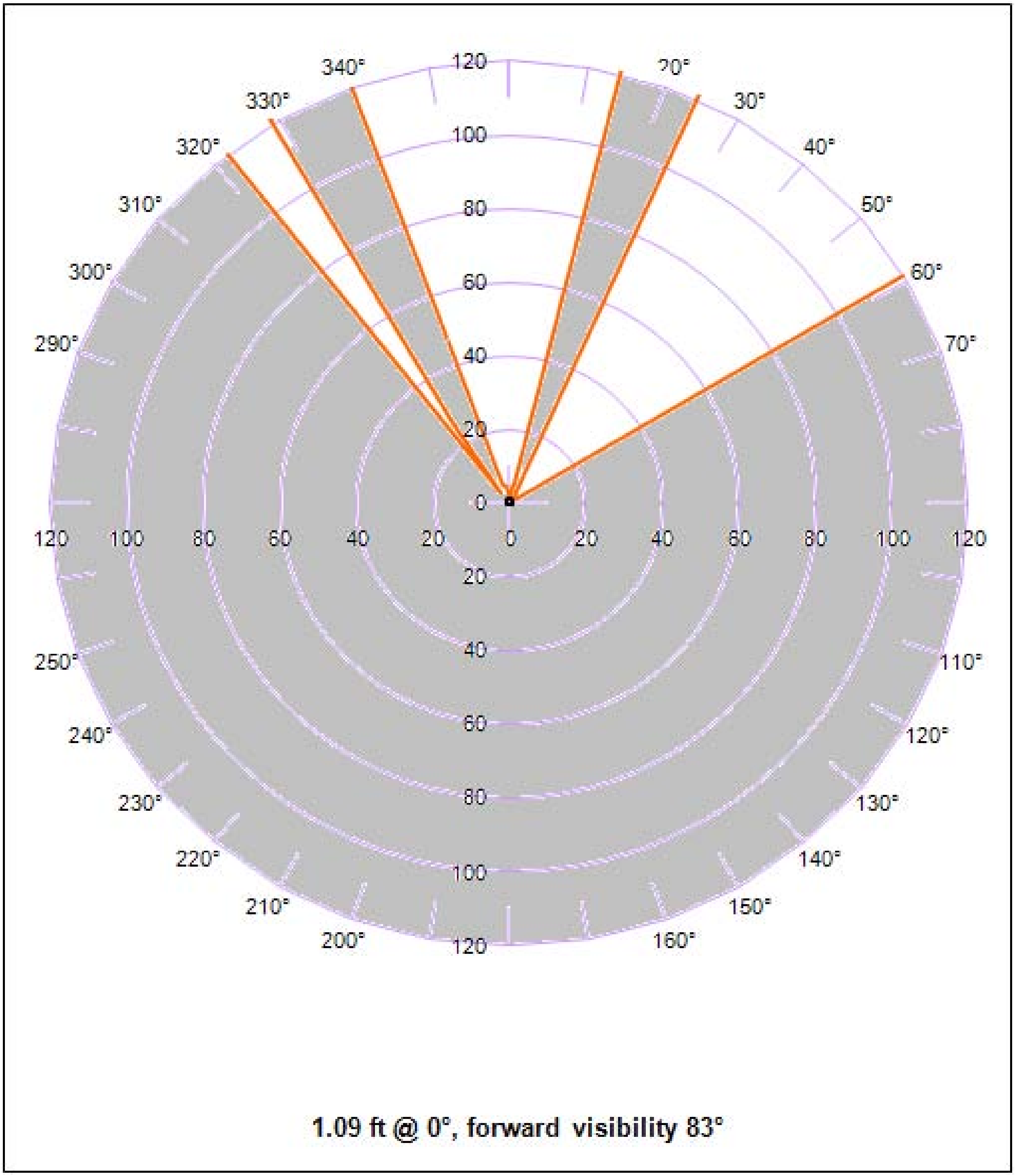
g. Camera zoom and Field of View (FOV). FOV testing was conducted in accordance with MIL-STD-1472F, paragraph 5.12.5.1. FOV measurements of the Xxxx were taken with the Xxxx in the xxxx pose and with the xxxx in the up position. FOV measurements were taken through the xxx, xxx, xxx, and xxx cameras. Measurements were taken to determine the overall FOV for each camera. Data were collected on a flat level surface with the cameras positioned over the center of the turning circle. Data points were recorded in 10^o increments to define FOV.

(1) Xxxx camera, xxx pose. The FOV for the xxxx camera in xxxx pose is illustrated in Figure 2.20-9. The forward visual field of view for the xxxx camera in xxxx pose was 83^o. The minimum ground view at all distances beyond 3 m (10 ft) at 0^o was 0.33 m (1.09 ft), which met the requirement according to MIL-STD-1472F, paragraph 5.12.5.2. The obstructions between 329^o and 340^o and 14^o and 24^o were because the xxxx were in the up position.

(2) Xxxx Camera, xxxx pose. The FOV for the Xxxx Camera in xxxx pose is illustrated in Figure 2.20-10. The forward visual field of view for the Xxxx Camera in xxxx pose was 46^o. The minimum ground view at all distances beyond 3 m (10 ft) at 0^o was 0.26 m (0.84 ft), which met the requirements according to MIL-STD-1472F, paragraph 5.12.5.2. The obstruction between 9^o and 16^o was because the flipper on the right side was in the up position.

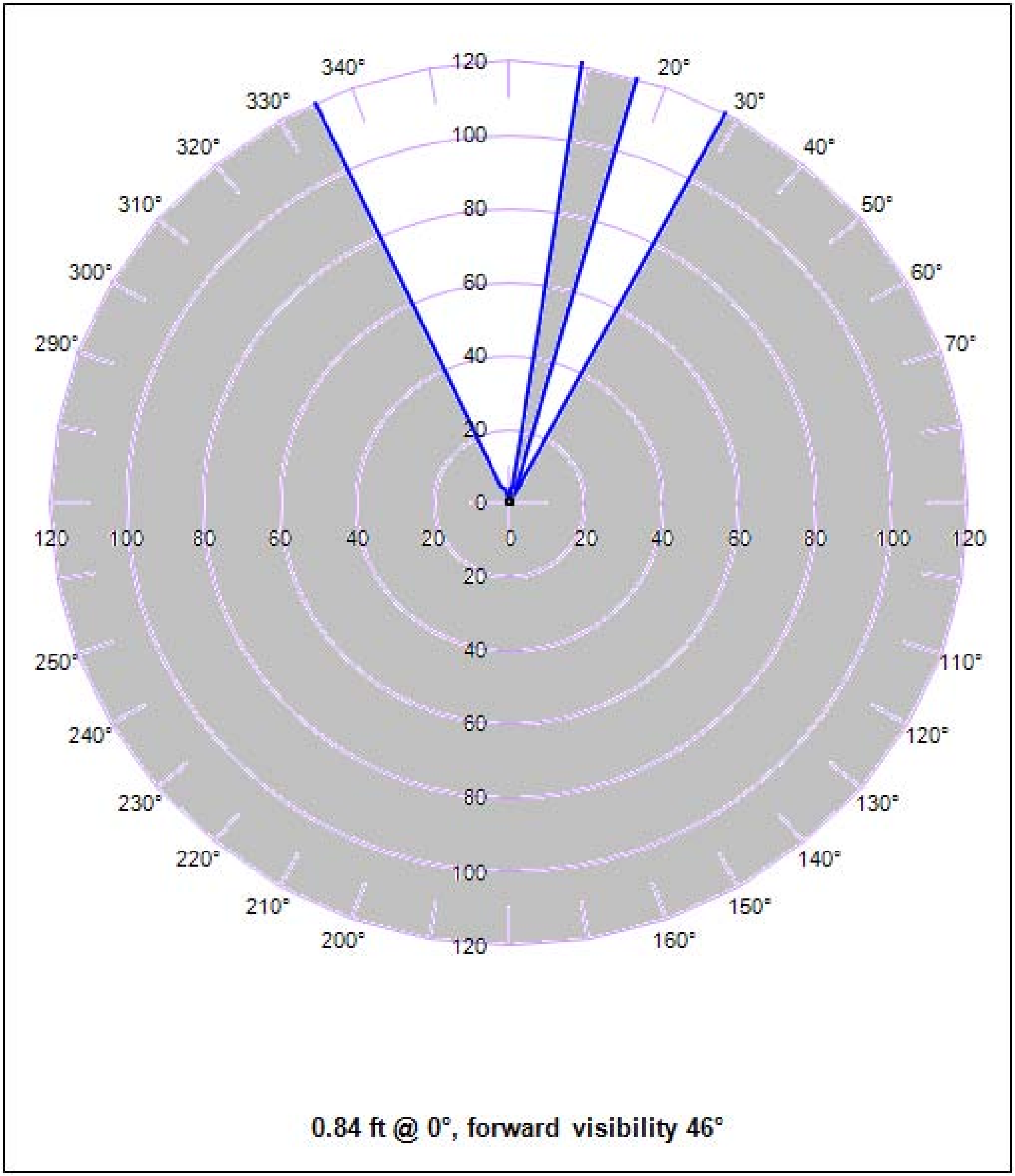
(3) Xxxx Camera, Xxxx pose. The FOV for the Xxxx Camera in xxxx pose is illustrated in Figure 2.20-11. The forward visual field of view for the Xxxx Camera in xxxx pose was 51^o. The minimum ground view at all distances beyond 3 m (10 ft) at 0^o was 0.4 m (1.29 ft), which met the requirements according to MIL-STD-1472F, paragraph 5.12.5.2. The obstruction between 16^o and 22^o was because the flipper on the right side was in the up position.

(4) Xxxx Camera, Xxxx pose. The FOV for the Xxxx camera in xxxx pose is illustrated in Figure 2.20-12. The forward visual field of view for the Xxxx camera in xxxx pose was 92^o. The minimum ground view at all distances beyond 3 m (10 ft) at 0^o was 0.1 m (0.33 ft), which met the requirements according to MIL-STD-1472F, paragraph 5.12.5.2.



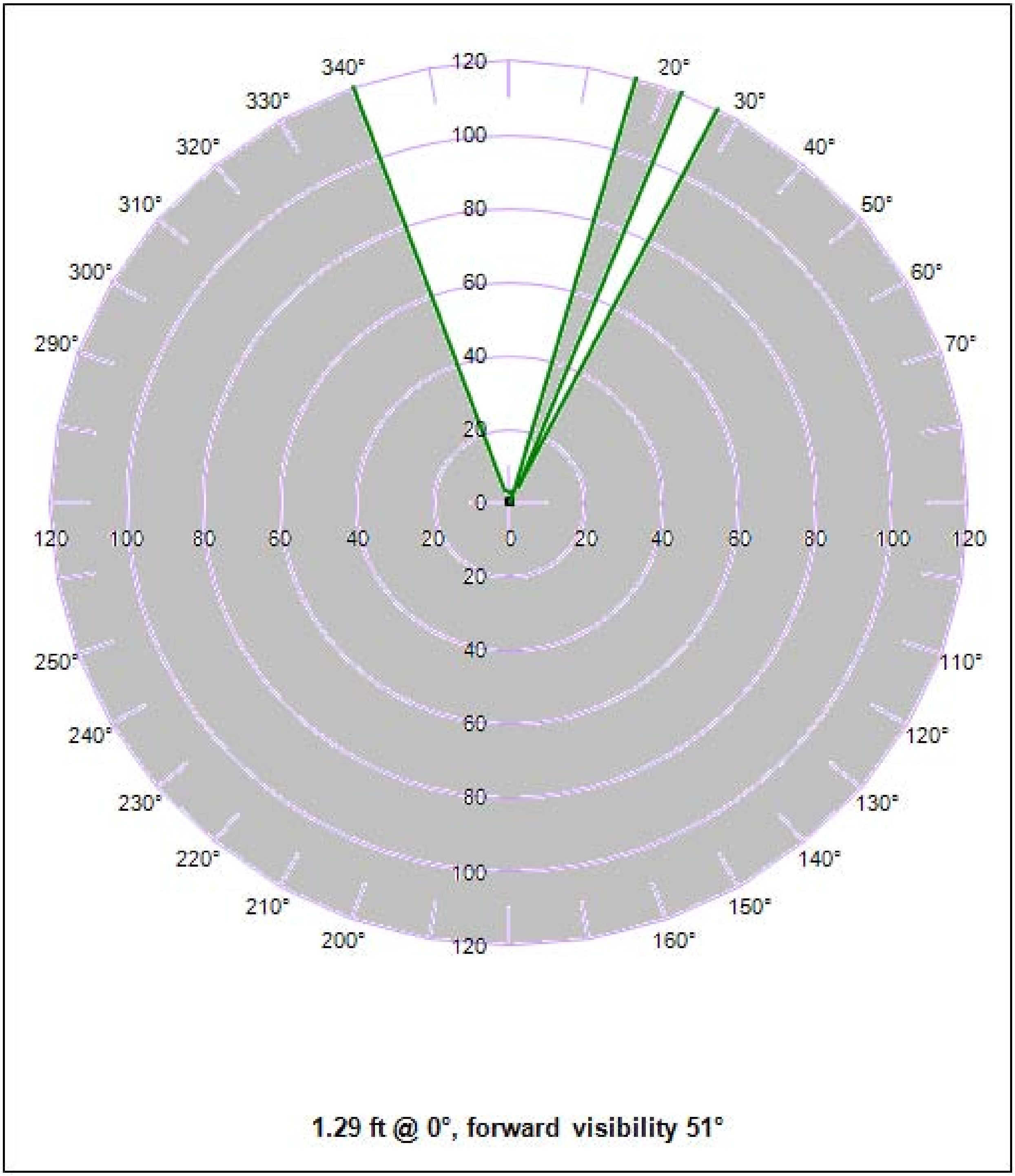
Note: Ground distance measured in feet; the shaded area indicates obstructed or non-visible view.

Figure B-2.20-9. FOV from xxxx camera, xxxx pose, Xxxx.



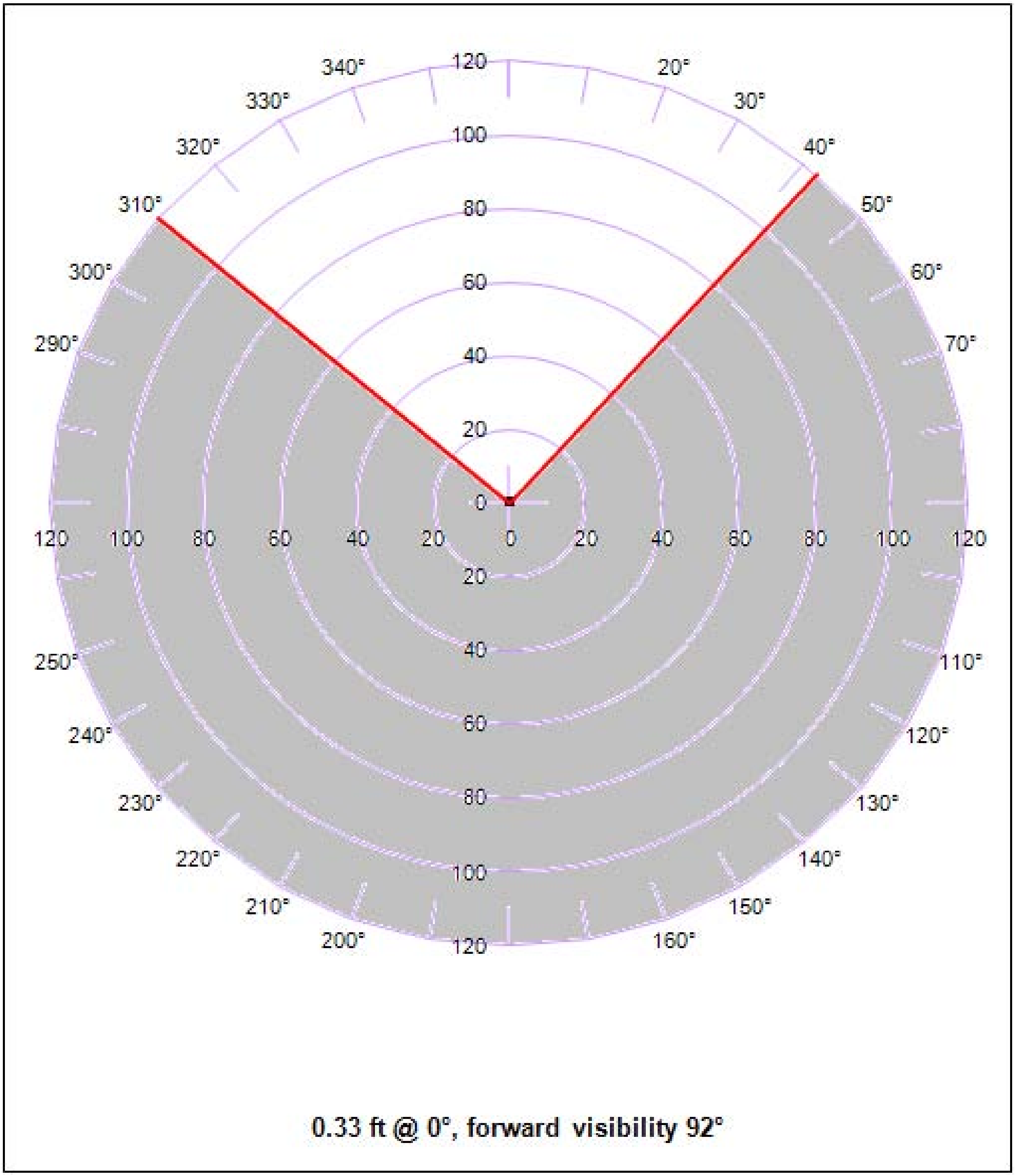
Note: Ground distance measured in feet; the shaded area indicates obstructed or non-visible view.

Figure B-2.20-10. FOV from xxxx camera, xxxx pose, Xxxx.



Note: Ground distance measured in feet; the shaded area indicates obstructed or non-visible view.

Figure B-2.20-11. FOV from Xxxx camera, xxxx pose, Xxxx.



Note: Ground distance measured in feet; the shaded area indicates obstructed or non-visible view.

Figure B-2.20-12. FOV from Xxxx camera, xxxx pose, Xxxx.

6.8.2 Standard Obstacles Data Example.

c. Trench Crossing.

The Xxxx was operated across a “V’ profile to determine if any points of contact other than the track make contact with the ground surface. Figure 2.7-2 displays the V-ditch obstacle used for this test. Figure 2.7-3 shows the dimensions of the obstacle.

Figure 2.7-2. V-Ditch.

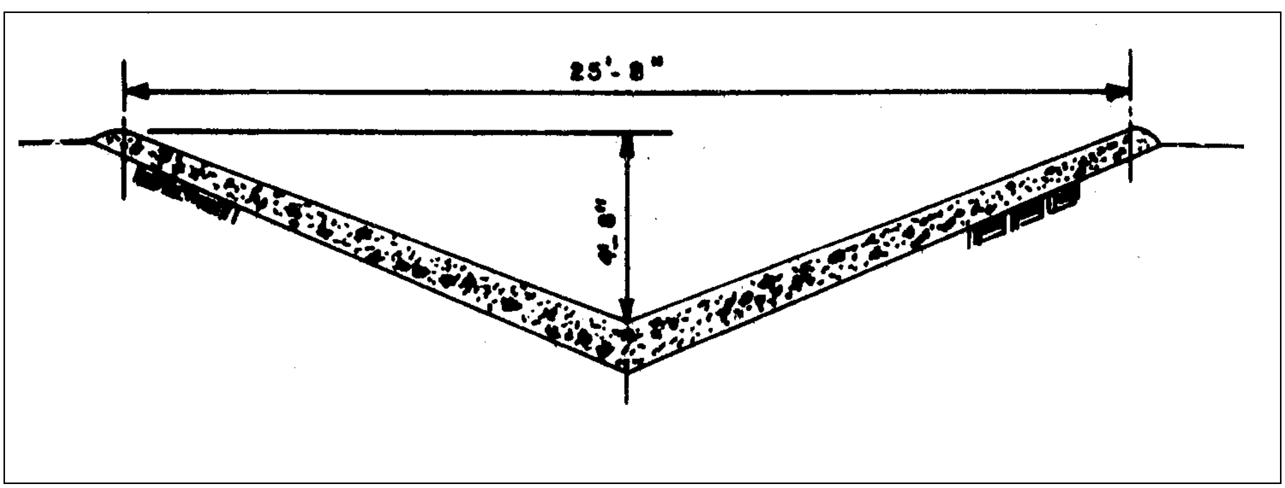


Figure 2.7-3. Cross-Section of V-Ditch.

The Xxxx was operated to the edge of the V-ditch, and was slowly operated across the obstacle. Upon descending the V-ditch, it was recorded that the nose of the Xxxx made contact with the opposite side of the V-ditch causing minor damage. After initial contact, the Xxxx was successfully able to traverse the V-ditch and ascend to the other side.

6.8.3 Acceleration/Max Speed Data Example.

TABLE 2.7-2. FORWARD DIRECTION, GRAVEL

SELECTED SPEED	TEST RUN SPEED (MPH)					AVERAGE SPEED (MPH)
	1	2	3	4	5	
XXXX	0.60	0.61	0.60	0.60	0.60	0.60
XXXX	3.05	2.98	3.03	3.05	2.99	3.02
XXXX	5.90	5.98	5.90	6.14	6.06	6.00

TABLE 2.7-3. FORWARD DIRECTION, GRASS

SELECTED SPEED	TEST RUN SPEED (MPH)					AVERAGE SPEED (MPH)
	1	2	3	4	5	
XXXX	0.59	0.59	0.59	0.59	0.59	0.59
XXXX	2.97	2.99	2.91	2.89	2.91	2.93
XXXX	5.98	5.98	5.98	5.90	5.68	5.90

TABLE 2.7-4. FORWARD DIRECTION, PAVED

SELECTED SPEED	TEST RUN SPEED (MPH)					AVERAGE SPEED (MPH)
	1	2	3	4	5	
XXXX	0.60	0.59	0.59	0.58	0.59	0.59
XXXX	2.98	2.96	2.97	2.95	2.98	2.97
XXXX	5.88	5.98	6.06	5.80	5.94	5.93

b. Reverse. The test was repeated with the xxxx operating in the reverse direction. The results, displayed in MPH, are presented in Tables 2.7-5 through 2.7-7.

TABLE 2.7-5. REVERSE DIRECTION, GRAVEL

SELECTED SPEED	TEST RUN SPEED (MPH)					AVERAGE SPEED (MPH)
	1	2	3	4	5	
XXXX	0.60	0.60	0.60	0.60	0.60	0.60
XXXX	2.36	2.41	2.36	2.40	2.41	2.39
XXXX	6.06	5.90	5.90	5.98	6.06	5.98

TABLE 2.7-6. REVERSE DIRECTION, GRASS

SELECTED SPEED	TEST RUN SPEED (MPH)					AVERAGE SPEED (MPH)
	1	2	3	4	5	
XXXX	0.60	0.60	0.59	0.60	0.60	0.60
XXXX	2.38	2.36	2.33	2.41	2.40	2.38
XXXX	5.88	6.06	5.83	6.06	5.90	5.95

6.8.4 Braking Data Example.

TABLE 2.7-3. SERVICE BRAKE STOP RESULTS XXXX T, REVERSE GEAR

METHOD OF BRAKE APPLICATION	ROAD SPEED, MPH	STOPPING DISTANCE	
		M	FT
DIRECT MODE			
Throttle release	5.6	1.1	3.8
Joystick bump	5.6	0.9	3.0
E-stop button	5.6 [a]	1.1	3.5
INDIRECT MODE			
Throttle release	3.6	2.0	6.5
	5.6	3.0	10.0
Joystick bump	3.6	0.4	1.3
	5.6	1.0	3.3
E-stop button	3.6	0.5	1.8
	5.6 [a]	0.9	3.0
a = Engine stalled			

6.8.5 Vehicle Fine Control Data Example.

a. Analysis.

(1) The steering and controllability of the Routerunner equipped HMMWV was assessed by comparing the operation of an identical vehicle using multiple test drivers over a variety of terrains and path following challenges.

(2) Data were collected from a variety of sources for use in the analysis. Global Positioning System (GPS) data were used to measure the speed over ground of the vehicle and its general position on each test course. GPS coordinate data could not be resolved to a level accurate enough to provide comparison between vehicle operating configurations. For each trial, the operator was requested to maintain a specific road speed to the best of his/her ability, whether operating the HMMWV in a conventional manner or tele-operating the vehicle. Speed

data were then statistically compared for similar operating configurations. The ability to maintain/control speed was evaluated using the mean and standard deviation from the measured speed and throttle position data. Both statistical parameters were computed from the requested speed and not the scatter of the measured data.

(3) Additional sensors applied specifically for test purposes were also used to assess the controllability of the vehicle. The manned operations were used as a baseline for acceptable performance. The vehicle was equipped with a steering wheel encoder calibrated to measure steering wheel angle. A six degree of freedom inertial rate and acceleration transducer was placed at the vehicle's center of mass. The measured 3-axis rate and acceleration were also used to determine the path following capability of the vehicle as well as the severity of the maneuvers. In order to use these data to assess controllability, some general understanding of vehicle dynamics is required. Study of the steering angle data showed some variability as a function of time, whether the system was manned or remotely operated. The compliance of the steering system contributed to the observed variability. Small angular changes in the steering wheel did not result in any measured changes to the road wheels or a corresponding change in direction to the vehicle. Before a change in heading takes place, the mechanical tolerances and frictional forces in the joints and links of the steering system must be overcome. For a manned system this process is quickly learned by the operator and is generally a function of the vehicle type and condition. This mechanical feedback built into the steering system was not available to the operator during unmanned operation. The operator must wait for, or anticipate the vehicle deviation from the path and then correct the heading using his/her judgment. The steering inputs for the unmanned operations were not smooth or continuous. Comparison of the steering angle data for straight line operations illustrated the driving style difference between manned and unmanned scenarios. Continuous, but small angular corrections were observed for all manned operations. Very little difference was noted between runs or operators during the manned trials. Less frequent, but very large steering inputs were necessary to keep the unmanned vehicle on the same path. The larger steering corrections in the unmanned mode also contributed to the road speed variability observed. Much more run-to-run variation was present between operators during the unmanned tests. Steering wheel corrections exceeding $\pm$10 degrees were noted for all of the operators and all speeds up to 45 mph.

(4) Operators were only able to control the vehicle speed at requested target speed up to 25 mph, independent of the required steering maneuvers in the tele-operated mode. Both operators used during the testing provided similar results. Above 25 mph there were large discrepancies in speed control between drivers and between operating scenarios. Unmanned operations were 7 to 23 mph slower than the requested speed for the straight line paths for requested speeds up to 45 mph, which was the maximum speed attempted. Differences in driver performance were also noted, although the run-to-run performance of each individual driver remained relatively constant. When steering inputs were required for changing vehicle direction, the speed variations noted during the straight line tests were further aggravated. Constant speeds of 20 to 25 mph were noted in the turning maneuvers regardless of the requested speed. Much more variability in the throttle position was noted for the steering maneuvers compared to the straight line tests, indicating driver control difficulties. Although the drivers were able to safely maintain a stable vehicle path it appears they sacrificed vehicle speed to do so. This may prove troublesome when using the routerunner as an escort vehicle for convoys.

(5) The HMMWV platforms are very forgiving for variations in steering inputs as determined during previous steady state and transient vehicle dynamics tests. As a rule, the HMMWV demonstrates understeering behavior throughout the range of available lateral acceleration. An understeering vehicle will require additional steering input in the direction of a turn as the speed and/or lateral acceleration increase or the turn radius decreases. As the vehicle reaches its lateral acceleration limit, additional steering in the direction of the turn will not result in any decrease in the turning radius. Also, applying brakes to assist with the vehicle control in this scenario will help restore the path of the vehicle without creating yaw instability. Yaw instability is generally responsible for triggering most single vehicle or trip rollover situations. Applying more steering and/or using the service brakes in this type of situation are instinctive for most drivers. Also, for the linear range of operation with this vehicle, a constant amount of steering input will result in a predictable increase in lateral acceleration. As the operator approaches the lateral acceleration limit, additional steering input is necessary, giving the vehicle higher steering sensitivity and additional driver feedback. The additional steering input during straight line “convoy type” operations does not appear to degrade the vehicle performance by any measured amount using the vehicle reaction (yaw rate and lateral acceleration) data. The lateral acceleration levels measured during the unmanned steering correction maneuvers were well below the lateral acceleration limits of the vehicle resulting in very predictable handling traits. The primary concern, albeit subjective in nature, is the additional burden on the operator during the unmanned scenarios. Significantly more attention is required when operating the vehicle, and failure to react to any unwanted vehicle motion could result in the vehicle leaving its intended lane of travel. The additional steering inputs are illustrated in the steering position histograms presented in Appendix B.

(6) The operations during steady state turning on primary roads from a handling/stability perspective appear closer between manned and unmanned scenarios only because the steering angles required to negotiate the prescribed turn resulted in larger steering angles for the manned scenarios. Lack of steering feedback to the operator during the unmanned testing resulted in more frequent and higher amplitude steering corrections for the unmanned runs. There was little difference in operation noted between operators in the tele-operated mode.

(7) Unmanned transient steering maneuvers exhibited similar steering profiles to the steady state maneuvers with multiple high amplitude steering corrections required at specific time intervals to maintain the vehicle path. The time intervals decreased as the road speed increased. If a periodic steering correction was missed or misjudged, the next input was exaggerated to regain the specified vehicle path. The predictable steering response and good overall vehicle stability of the HMMWV prevented these actions from causing a loss of vehicle control.

(8) Secondary road speeds were decreased compared to the primary road operations for both manned and unmanned conditions. This was considered more a factor of the HMMWV handling than the mode of vehicle operation. The reduction in available tractive and lateral forces due to the dirt road surface changed the handling balance of the vehicle. Operating under these conditions, the HMMWV developed a more neutral steering characteristic. In the case of a neutral steering vehicle the operator plays a more significant role in the handling/control of the

vehicle. The ability to use the throttle, brakes, and steering can impact whether the vehicle understeers or oversteers at even moderate levels of lateral acceleration.

(9) Understeering vehicle behavior was described in preceding discussion and is an inherently safe operating state. An understeering vehicle allows the driver to employ instinctive driving techniques, e.g. more steering and braking, to regain control of the vehicle. An oversteering vehicle requires the operator to steer in the opposite direction of travel and possibly apply throttle to regain control. These driving traits are situation-dependent and must be learned/practiced by most drivers. These responses are not instinctive responses to a situation where a loss of control is possible. This temporary loss of control was experienced several times during the exit of the decreasing radius turns on the secondary road test course. Use of visual cues only during operations under these conditions is not considered sufficient. When driving a transition vehicle the feedback from the vehicle through the steering system is essential to maintain control. Speeds exceeding 20 mph in off-road conditions resulted in the HMMWV transitioning from a predictable understeering configuration to a less desirable handling configuration. Operators had more difficulty maintaining the requested vehicle speed while manned or tele-operating the same vehicle. During the manned trials, drivers inadvertently slowed their speeds in the turns based on the feedback from the vehicle. The drivers' speed disparities further increased in the tele-operated mode.

b. Conclusions.

(1) Operator driving techniques were very different between manned and unmanned trials.

(2) The steering inputs necessary to maintain vehicle control during the unmanned trials were not smooth, and their amplitudes were generally 10 times those observed during the manned trials.

(3) The HMMWV platform is very forgiving for differences in driving techniques as long as sufficient traction is available.

(4) Maintaining target speeds in the tele-operated mode proved more difficult than the manned mode. This may have a negative input on the convoy lead role of the Routerunner.

(5) Highway operations can be safely conducted at speeds up to 45 mph. Operator times should be monitored closely as speed increases due to the increased amount of mental activity required to maintain vehicle control.

(6) Off-road operations should be limited to 20 mph or less due to the reduction in vehicle control and oversteering behavior when cornering.

6.8.6 OCU Usefullness Data Example.

(8) The performance of the color xxxx camera far exceeded the requirement with a 63 percent correct Recognition out to 820 m (12,690 ft). A summary of the Recognition results are presented in Table 2.20-5. Sample color images taken with the OCU at different ranges are shown in Figure 2.20-4.

TABLE 2.20-5. SUMMARY OF RECOGNITION RESULTS FOR Xxxx COLOR CAMERA DURING DAYLIGHT CONDITIONS

RANGE		**CORRECT RECOGNITION (PERCENT)**
m	**ft**	
80	262	92
120	394	96
160	525	96
200	656	96
240	787	96
270	886	100
290	951	94
310	1017	86
330	1083	97
350	1148	86
370	1214	100
390	1280	83
410	1345	92
420	1378	75
570	1870	75
620	2034	75
750	2461	67
820	2690	63

DCU – Weapon at 120 m | ACU – Pack at 510 m | Civilian Half – Shovel at 820 m

Note: Image quality has not been changed; images have been cropped on left and right side to show side by side.

Figure 2.20-4. Sample color images taken during camera performance testing, all images are from Xxxx T-110.

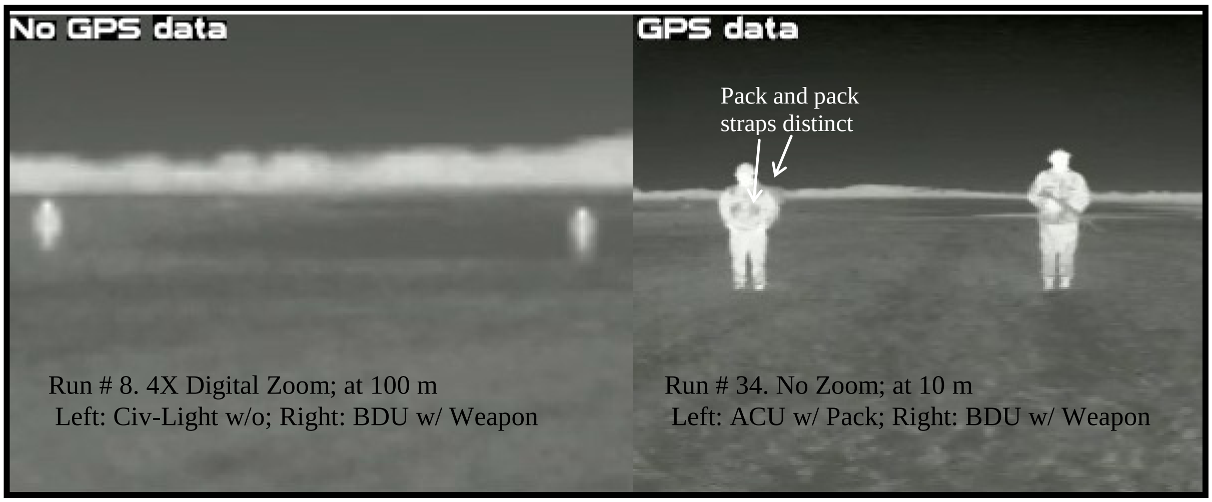
(9) The color camera had high picture quality incorporated with a 36X optical zoom and 12X digital zoom provided exceptional detection capability during daylight hours in full sun and cloudy conditions.

c. Thermal sensor recognition. The thermal testing was conducted in a similar manner as the color camera performance. The test did not start until the end of Astronomical twilight on the evening of 20 March 2009. A training run was performed prior to the start of the test. All ten targets were lined up in a row, similar to Figure 2.20-5, each observer viewed the targets through the Xxxx thermal camera and each target was identified to them. The thermal recognition test started with the targets 100 m (328 ft) from the observers, and the ranges were then incrementally decreased by 10 m.

The Thermal Camera had a correct recognition of 4 percent at 100 m (328 ft) and 71 percent at 10 m (33 ft). A summary of the correct recognition results is shown in Table 2.20-6. Sample thermal images taken with the OCU at different ranges is shown in Figure 2.20-5.

TABLE 2.20-6. SUMMARY OF RECOGFNITION RESULTS FOR Xxxx THERMAL SENSOR DURING NIGHTIME CONDITIONS

RANGE		CORRECT RECOGNITION (PERCENT)
m	ft	
10	33	71
20	67	21
40	131	29
60	197	17
80	262	13
100	328	4



Note: Image quality has not been changed; images have been cropped on left and right side to show side by side.

Figure 2.20-5. Thermal images from Xxxx T-119

As displayed in the thermal images above at 100 m, even with the sensor zoomed in fully, the targets were not recognizable. At 10 m, some distinct features could be recognized, especially when additional zoom was applied, such as the straps for the pack on the chest on the 6-ft target as well as part of the pack showing over the shoulder. The right target was holding a weapon. The thermal camera, unlike the Xxxx Camera, has a digital zoom and not an optical zoom. When zooming in, 2X or 4X digitally enlarges the existing pixels within the FOV of the image which only increased the image size but did not increase the resolution.

d. Indoor sensor demonstration. A demonstration of the sensors performance was conducted inside building 714G on 16 March 2009 to document any vulnerabilities related to different lighting conditions, Metal Halide and Fluorescent lighting and total darkness. Objects and barriers were set up in the three room building, and personnel or targets were positioned in each room. The operator, using the sight of the cameras/sensors on the Xxxx, negotiated it through the building, taking an image of each target found and all exit doors. The test was performed with the color camera and the lights “on”, the camera mode with IR illuminator “on” and the thermal sensor mode with the lights “off”. A video clip of each of the three trials was recorded during the entire trial. Sample images from the Xxxx cameras/sensors for each trial are presented in Figures 2.20-6 through 2.20-8. There were no issues evident from the video clips or the images taken with the Xxxx in any of the modes with or without the lights “on”.

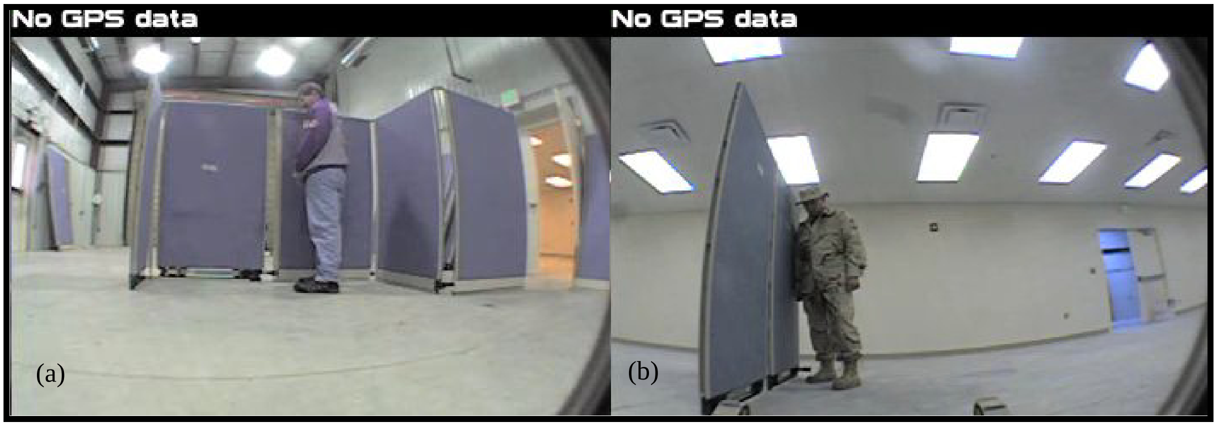


Figure 2.20-6. Color image from xxxx camera under (a) Metal Halide and (b) Fluorescent lighting.

Figure 2.20-7. Camera mode with IR illuminator “on”, lights “off” in building.

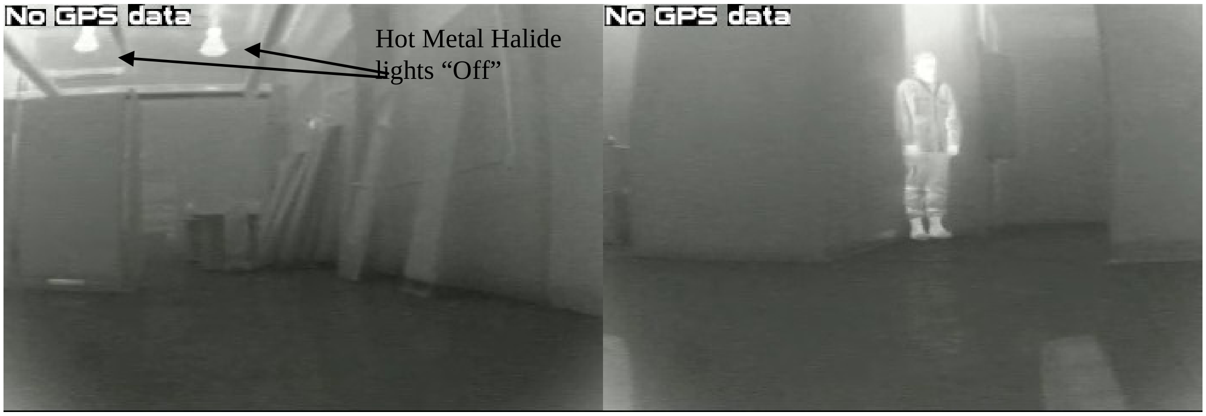


Figure 2.20-8. Sensor in Thermal mode, lights "off" in building.

e. Eye chart. Two operators utilized the xxxx, xxxx, and xxxx camera to read the top line of a standard eye chart. Table 2.20-7 lists the minimum and maximum distances, the operators were able to correctly read the top line of the standard eye chart using each camera.

TABLE 2.20-7. MINIMUM AND MAXIMUM DISTANCES FOR EACH CAMERA

CAMERA	MINIMUM RANGE, m (ft)	MAXIMUM RANGE, m (ft)
Chassis	0.3 (1.0)	2.9 (9.5)
Drive	0.3	3.0 (10)
Xxxx	0.3	240 (787)

f. IED identification. Three IED were placed in a simulated town center. The XXXX was operated through the town center with the operator located outside of viewing distance. The XXXX was stopped when the operator located an IED and the distance between the XXXX and the IED was recorded. The distances the operator was able to detect the IED are shown in Table 2.20-8.

TABLE 2.20-8. DISTANCES FROM THE IED UPON DETECTION

TRIAL	DISTANCE	
	METERS	FEET
1	0.69	2.3
2	3.61	11.8
3	0.46	1.5
4	2.11	6.9
5	0.66	2.2
6	8.38	27.5
7	0.00	0.0
8	0.00	0.0
9	0.28	0.9
10	1.88	6.2
11	5.44	17.8
12	4.32	14.2
Average	2.31	7.6

The average distance from the XXXX to the IED was 2.31 m (7.6 ft). In seven of the twelve trials, the XXXX was within 2 m (6.6 ft) of the IED. The operators were not trained and did not have any previous experience in identifying and locating IEDs.

g. Camera zoom and Field of View (FOV). FOV testing was conducted in accordance with MIL-STD-1472F, paragraph 5.12.5.1. FOV measurements of the Xxxx were taken with the Xxxx in the xxxx pose and with the xxxx in the up position. FOV measurements were taken through the Xxxx, Xxxx, Xxxx, and Xxxx cameras. Measurements were taken to determine the overall FOV for each camera. Data were collected on a flat level surface with the cameras positioned over the center of the turning circle. Data points were recorded in 10^o increments to define FOV.

(1) Xxxx camera, Xxxx pose. The FOV for the xxxx camera in xxxx pose is illustrated in Figure 2.20-9. The forward visual field of view for the xxxx camera in xxxx pose was 83^o. The minimum ground view at all distances beyond 3 m (10 ft) at 0^o was 0.33 m (1.09 ft), which met the requirement according to MIL-STD-1472F, paragraph 5.12.5.2. The obstructions between 329^o and 340^o and 14^o and 24^o were because the xxxx were in the up position.

(2) Xxxx Camera, xxxx pose. The FOV for the Xxxx Camera in xxxx pose is illustrated in Figure 2.20-10. The forward visual field of view for the Xxxx Camera in xxxx pose was 46^o. The minimum ground view at all distances beyond 3 m (10 ft) at 0^o was 0.26 m (0.84 ft), which met the requirements according to MIL-STD-1472F, paragraph 5.12.5.2. The obstruction between 9^o and 16^o was because the flipper on the right side was in the up position.

(3) Xxxx Camera, Xxxx pose. The FOV for the Xxxx Camera in xxxx pose is illustrated in Figure 2.20-11. The forward visual field of view for the Xxxx Camera in xxxx pose was 51^o. The minimum ground view at all distances beyond 3 m (10 ft) at 0^o was 0.4 m (1.29 ft), which met the requirements according to MIL-STD-1472F, paragraph 5.12.5.2. The obstruction between 16^o and 22^o was because the flipper on the right side was in the up position.

APPENDIX A. ABBREVIATIONS.

DoD	Department of Defense
FOV	Field of View
IR	Infrared
JAUS	Joint Architecture of Unmanned Systems
JGRE	Joint Ground Robotics Enterprise
OCU	Operator Control Unit
RF	Radio Frequency
SUT	System under test
TIRS	Test Incident Reports
TOP	Test Operations Procedure
UGV	Unmanned Ground Vehicle

APPENDIX B. REFERENCES.

1. TOP 02-2-540, Testing of Unmanned Ground Vehicles, 12 February 2009.

2. TOP 02-2-542, Safe Operation of Weaponized Unmanned Ground Vehicle (UGV) Systems, 13 Jul 2010.

3. DTC Policy Bulletin No. 1-09, Software Safety Verification Policy and Guidelines, 29 July 2009.

4. TOP 03-2-812, Field of Vision, 16 December 2009.

For information only (related publications).

a. Unmanned Systems Safety Guide for DoD Acquisition, First Edition, (Version .96), Jan 2007.

Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Test Business Management Division (TEDT-TMB), US Army Developmental Test Command, 314 Longs Corner Road Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: TEDT-AT-AD-F, U.S. Army Aberdeen Test Center, 400 Colleran Rd., APG, MD 21005-5055. Additional copies are available from the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.