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14. ABSTRACT
This TOP describes the procedure to quantify the thermal comfort of a truck cab in temperatures as hot and humid as possible. Facilities, instrumentation, health and safety, test conditions, test procedures, data required, and presentation of data will be discussed in this TOP.

15. SUBJECT TERMS

Heat Soak	Ventilation	Human Testing
Solar Load	Thermal Comfort	Heat Stress

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US ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

Test Operations Procedure TOP 1-2-807 9 October 2007
DTIC AD No.

THERMAL COMFORT TESTING FOR VEHICLE OPERATOR/PASSENGER WORKSPACES (TRUCK CABS)

1. SCOPE.

The scope of this TOP is to quantify the thermal comfort of a truck cab in temperatures and humidity's as extreme as possible. Temperature and air speed data as well as subjective data from cab occupants will be gathered.

This TOP will supplement the following TOPs:

TOP 1-1-006[1**]
TOP 2-2-508[2]
TOP 2-4-001[3]
TOP 10-1-003[4]

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

The facilities used for thermal comfort testing shall provide test courses that are able to accommodate an abbreviated worse case scenario of a day's mission for the test truck. Testing should follow an abbreviated mission scenario of the truck as closely as possible to ensure realistic data. Possible courses are a paved level course, a level gravel course, a level cross country course, a low rolling hills course, and a high hills course.

** Superscript numbers correspond to those in Appendix D, References.

2.2 Instrumentation.

Devices for Measuring Temperature	Measurement Accuracy
Surface Thermocouples (TC) T Type (dry bulb temperature)	Range >0 to 350°Celsius (C) (>32 to 662°Fahrenheit (F)) Tolerance ± 1.0°C (±1.8°F)
Wet Bulb Globe Temperature (WBGT)	Range 0 to 100°C (32°F to 212°F) .622 °C (1.12 °F)
Wet Bulb Temperature	±0.6°C (±1°F)
Black Globe Temperature (measures radiant heat)	Range >0 to 350°C (>32 to 662°F) Tolerance ± 1.0°C (±1.8°F)

Devices for Measuring	Measurement Accuracy
Platform scales or portable wheel (scales to weigh test truck)	300,000 pounds ± 50 136,078 kilograms ± 23
Humidity Probe	Range 3% to 95% Tolerance ±2%
Hot Wire Anemometer (air speed)	Tolerance 1.5% feet/second @ room temp
Vane Anemometer (air speed)	±2.5% of feet/second ±0.25% of reading
Mast with TC; T Type	Range >0 to 350°C (>32 to 662°F) ± 1.0°C (1.8°F)
Pyranometer (measures natural and reflected solar radiation)	Spectral response waveband: 310 to 2800 nm Maximum irradiance: 2,000 Watts/meter^2 Uncertainty < ±2.5%
Micrometer (measures ventilation registers)	0.000001 inch .00000254 centimeter
Infrared (IR) Thermometer (handheld)	Range -18 to1370°C (0 to 2500°F) Tolerance ±1 of reading
IR Camera	-40°C to 120°C Tolerance ±2% or 2°C of reading
Digital Camera	3 Mega Pixels or better
Data Logger (multi-channel)	40 Channels

3. REQUIRED TEST CONDITIONS.

a. Conditions should be as hot and humid as possible. The minimum temperature and relative humidity to use this TOP are an outside temperature of 85°F (29°C) or a minimum outside relative humidity of 55%.

b. Truck is payloaded to gross vehicle weight as defined in the vehicle's technical manual. Verify that the payload is properly secured.

c. Perform any Preventive Maintenance Checks and Services (PMCS).

d. In order to observe air turbulence or lack of it, attach several equal-length strips of survey tape or other light material at various locations inside the truck cab.

e. The test truck shall be instrumented as follows:

(1) The roof of the truck cab is divided into equal sections of one foot square, if possible. Surface TCs are placed in the center of each section of cab roof, one on the exterior and one on the interior.

(2) Install a pyranometer on the exterior of the middle of the truck cab.

(3) A surface TC is placed on the bottom and center of the left half of the windshield inside the cab. Another surface TC is placed on the bottom and center of the right half of the windshield inside the cab.

(4) A surface TC is placed at the center of the floor space for the driver and all other passenger locations within the cab.

(5) A surface TC is placed at the center of each side and rear wall within the truck cab.

(6) If the test truck has a "dog house" (engine cover or cowling) within the cab, surface TCs are centered on the front, top, and rear of the "dog house". Also, surface TCs are placed on either side of the "dog house" near the occupant or close to the occupant's leg.

(7) A TC is placed as close and centered to the surface of each ventilation register depending on the size, shape, and style of the ventilation register and the anemometer used.

(8) TCs are positioned to the side of the seat at the head, waist, and feet for the driver and system operator and each passenger. The TC is located to the side of each seat to prevent the TC from being damaged by a test participant getting in and out of the seat. The reference point for the head area is 24 inches, or 60.96 centimeters, above the center and back of the seat pan, see reference MIL-STD-1472F[5], Paragraph 5.12.6.1, Heating.

(9) The TC at the waist is less than one (1) inch, or 2.54 centimeters, above the back of the seat pan and the foot is six (6) inches, or 15.24 centimeters, above the floor. Secure the manikins in all empty seats.

(10) Install the WBGT in the middle, if possible, of the truck cab.

(11) Install the black globe in the middle, if possible, of the truck cab, refer to Figure 1.

Figure 1. Instrumentation installed in cab for Family of Medium Tactical Vehicles (FMTV)

(12) Install a TC in the area between the engine and the fire wall or "dog house".

(13) Install surface TCs at other locations, e.g., shifter handle, instrument panel, side windows, and locations identified as hot spots as described in Section 4.2 of this document.

(14) Install the temperature mast (a shielded TC on a bracket that extends three (3) feet (0.9 meter) from the front exterior of the test vehicle).

(15) If hot wire anemometers are to be installed at each ventilation register, refer to Appendix C for instructions on placement of the anemometers.

(16) Hot wire anemometers can also be installed in a grid just inside opened windows and hatches. The grid can be made of a metal grill or some other strong material. Initially use a vane anemometer to find the maximum, minimum, and average value for a particular trial condition, for instance, the vehicle moving 10 miles per hour (mph), or 16 kilometers per hour (kph). On a grid, install three (3) anemometers that are equidistant from each other and have the average air speed. For each additional trial condition, this procedure will need to be repeated to verify that the anemometers are in the average air speed locations.

(17) Connect all instrumentation to the multi-channel data storage device and set the sampling rate appropriately. A suggested sampling rate is once a second in order to capture the variations in temperature, air speed, and other data being collected. The sampling rate can be increased or decreased.

(18) Give consideration to a unique naming convention for the stored files. The Julian date, time, and shortened name for the type of test could be used.

(19) Take digital photos of installed instrumentation.

3.1 Health and Safety.

a. General.

Testing in the extreme environment proposed in this TOP will subject the truck operators (driver and system operator or passengers) to extreme heat stress. The following considerations need to be applied for the entire duration of the Thermal Comfort Testing.

(1) Test Officers, or **Soldiers in charge**, should review U.S. Army Research Institute of Environmental Medicine (USARIEM) Technical Note 95-1[6] or Technical Bulletin (TB) Medical (MED) 507[7] during the planning stage.

(2) All personnel involved in the test whether operating the test truck or conducting or observing the test **must** be acclimatized to the heat.

(3) Adequate cooled water, shade, and a covered rest area **should** be provided.

(4) The WBGT in the test truck and at the staging area/test site **should** be monitored and personnel kept informed of any change and reminded of the appropriate response.

(5) If appropriate and available, cooled clothing or other heat management techniques **should** be provided to those who are exposed to the heat for an extended period.

(6) All personnel **must** be monitored in order to identify at the earliest possible time any test personnel who is becoming heat stressed.

(7) Emergency Responders responsible for the test site **should** be involved in the test preparations in order that everyone on the test knows the hazards and the safety controls that are in place.

b. Severe Conditions.

To test for thermal comfort in a truck cab, it is necessary for humans to ride inside the test cab under extremely severe conditions. This situation is not to be taken lightly. Safety of the test participants is the primary concern. In order to quantify the environment of the thermal comfort test, criteria from MIL-STD-1472F that deal with ventilation and temperature are used and are listed below.

If any **ONE** of the following conditions exists, constant communication shall be maintained between those in the truck cab and those at the staging area:

(1) If temperatures are GREATER THAN 88°F or 31°C (comparable to the Corrected Effective Temperature of 85°F or 29.5°C, see reference MIL-STD-1472F, Paragraph 5.8.1.3, Air conditioning.) and no air conditioning is used.

(2) If outside fresh air is supplied at a minimum rate LESS THAN 20 feet ^{3} (0.57 meter ^{3})/minute/person, see reference MIL-STD-1472F, Paragraph 5.12.6.2, Ventilation.

(3) If the ventilation is LESS THAN 30 feet ^{3} (0.85 meter ^{3})/minute/person in a truck cab enclosure of 150 feet ^{3} (4.25 meters ^{3}) or less per person, see reference MIL-STD-1472F, Paragraph 5.8.1.2, Ventilating. (For larger cab enclosures see MIL-STD-1472F, Figure 35, for the minimum ventilation per person.)

(4) If air flow rates for temperatures above 90°F (32°C) are LESS THAN 150 feet ^{3} (4.2 meters ^{3})/minute/person. The reference is the same as was cited in 3.1.b.(2).

If any participant in the test truck cab begins to exhibit signs of HEAT STRESS DISORDER, the test will be IMMEDIATELY ABORTED.

4. TEST PROCEDURES.

4.1 Perform Safety Briefing.

Prior to the beginning of activity at the test site, the Test Officer, or **Soldier in charge**, shall ensure that the entire test crew is briefed on heat stress issues, including what they are, what the symptoms are at each level, and the appropriate First Aid.

Each day the Test Officer should brief the expected high temperature, the expected WBGT, and the emergency procedures to be followed should a heat stress incident occur.

4.2 Thermal Survey for Hot Spots.

Use a handheld IR Thermometer to survey the test truck while the engine is running to identify any potential interior cab heat contributors. Items for consideration are turbo chargers, exhaust systems, cooling systems, radiant heat sources, and any joints between the firewall and cab, "dog house" and cab, and any other possible points that could leak heat into the cab. Follow up by using a surface TC to measure temperatures on identified hot spots.

4.3 Heat Soak Test.

a. Perform Safety Briefing, see Section 4.1.

b. Before beginning the test, perform a Pilot Test to ensure instrumentation, specified in Section 3.e., is operational and all conditions for testing are correct.

c. Park the test truck in an open, unshaded area on dirt, if possible. If the truck were parked on asphalt, the asphalt would provide an unwanted additional source of radiant heat.

d. Orient the test truck in a north/south direction with the front of the truck facing south.

e. Close all windows and hatches.

f. It is useful to secure manikins in all empty seats.

g. If the test truck has been running, allow enough time for the engine and other heated systems to cool down before beginning the Heat Soak Test.

4.4 Ventilation with Temperature Measurements Testing.

a. Mechanical Ventilation Measurements with Truck Stationary.

(1) Perform Safety Briefing, see Section 4.1.

(2) Before beginning the test, perform a Pilot Test to ensure instrumentation, specified in Section 3.e., is operational and all conditions for testing are correct.

(3) Make a matrix or table of all possible combinations of the required ventilation system measurements; such as, air conditioning on or off, recirculate or fresh air, ventilation to face or foot, the blower at different speeds, and any other conditions. Table 1 is an example of a matrix. If the total number of trials is very large some of the trials may need to be eliminated to make more manageable and meaningful data sets.

TABLE 1. Matrix of Truck Cab Conditions for Mechanical Ventilation Measurements with Truck Stationary

Air Conditioning	Recirculate or Fresh	Setting of Ventilation	Blower Speed	Ventilation Register 1*	Ventilation Register 2*
ON	Recirculate	Face	Off	Air Velocity Measurement (AVM) 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
			Low	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
			High	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
		Foot	Off	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
			Low	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
			High	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
	Fresh	Face	Off	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
			Low	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
			High	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
		Foot	Off	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
			Low	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
			High	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3

*Have a column for each register measured in the truck cab.

TABLE 1. Matrix of Truck Cab Conditions for Mechanical Ventilation Measurements with Truck Stationary (Completed)

Air Conditioning	Recirculate or Fresh	Setting of Ventilation	Blower Speed	Ventilation Register 1*	Ventilation Register 2*
OFF	Recirculate	Face	Off	Air Velocity Measurement (AVM) 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
			Low	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
			High	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
		Foot	Off	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
			Low	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
			High	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
	Fresh	Face	Off	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
			Low	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
			High	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
		Foot	Off	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
			Low	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3
			High	AVM 1	AVM 1
				AVM 2	AVM 2
				AVM 3	AVM 3

*Have a column for each register measured in the truck cab.

(4) Close all windows and hatches before beginning the Mechanical Ventilation with Truck Stationary Test.

(5) Secure manikins in all empty seats.

b. Ventilation Measurements with Windows and Hatches Opened and Truck Moving.

(1) Perform Safety Briefing, see Section 4.1.

(2) Before beginning the test, perform a Pilot Test to ensure instrumentation, specified in Section 3.e., is operational and all conditions for testing are correct.

(3) Secure manikins in all empty seats.

c. Ventilation Measurements with Test Participants.

(1) Human Testing with Stationary Truck.

(a) Perform Safety Briefing, see Section 4.1.

(b) Before beginning the test, perform a Pilot Test to ensure instrumentation, specified in Section 3.e., is operational and all conditions for testing are correct.

(c) Have a test participant seated in each crew position--no manikins are to be used.

(d) Position the grills in the ventilation registers to allow maximum air flow to the most crew positions possible.

(e) Have all windows and hatches closed.

(f) Choose the worst, the best, and a medium set of test conditions from the matrix in Table 1. These three sets of conditions will be the environment in which the human testing is performed with truck stationary.

(2) Human Testing with Moving Truck.

(a) Perform Safety Briefing, see Section 4.1.

(b) Before beginning the test, perform a Pilot Test to ensure instrumentation, specified in Section 3.e., is operational and all conditions for testing are correct.

(c) Have a participant seated in each seat in the cab--no manikins are to be used.

(d) Choose conditions that are the worst, the best, and one between the two extremes. Consider whether all windows and hatches are to be opened or closed and which cases from the ventilation matrix, Table 1, are most applicable.

d. Thermal Comfort Performance Testing.

(1) Perform Safety Briefing, see Section 4.1.

(2) Before beginning the test, perform a Pilot Test to ensure instrumentation, specified in Section 3.e., is operational and all conditions for testing are correct.

(3) Have a participant seated in each seat in the cab--no manikins are to be used.

(4) Use a two (2) to three (3) hour segment of a mission scenario that is representative of the test truck. An example of a test truck mission day is the Heavy Equipment Transporter System (HETS) which was designed to transport an M1A1 Abrams and its crew to a forward area with a mission day of ten hours. The mission day assumes a period for loading, transporting, and unloading with a rest break and a lunch break of 30 minutes included in the 10 hours.

(5) Ensure that all equipment that would be powered up when the test truck is on a user-defined mission is powered up. Also, ensure the air conditioning, windows and hatches, blower speed, and anything else follows the user-defined mission profile.

(6) Operate the test truck at the rated speed for each course.

(7) If possible, have a different second group of participants who are unfamiliar with the test truck take a test ride under the same conditions as those in the Thermal Comfort Performance Testing.

5. DATA REQUIRED.

5.1 Thermal Survey for Hot Spots.

Document the locations and temperatures of all hot spots. Take digital photos of all hot spots.

5.2 Heat Soak Test.

a. Record data for at least a 24-hour period from all instrumented locations listed in Section 3.e.

b. Use an IR camera to record the IR signature of the outside of the test truck. Figure 2 is an example.

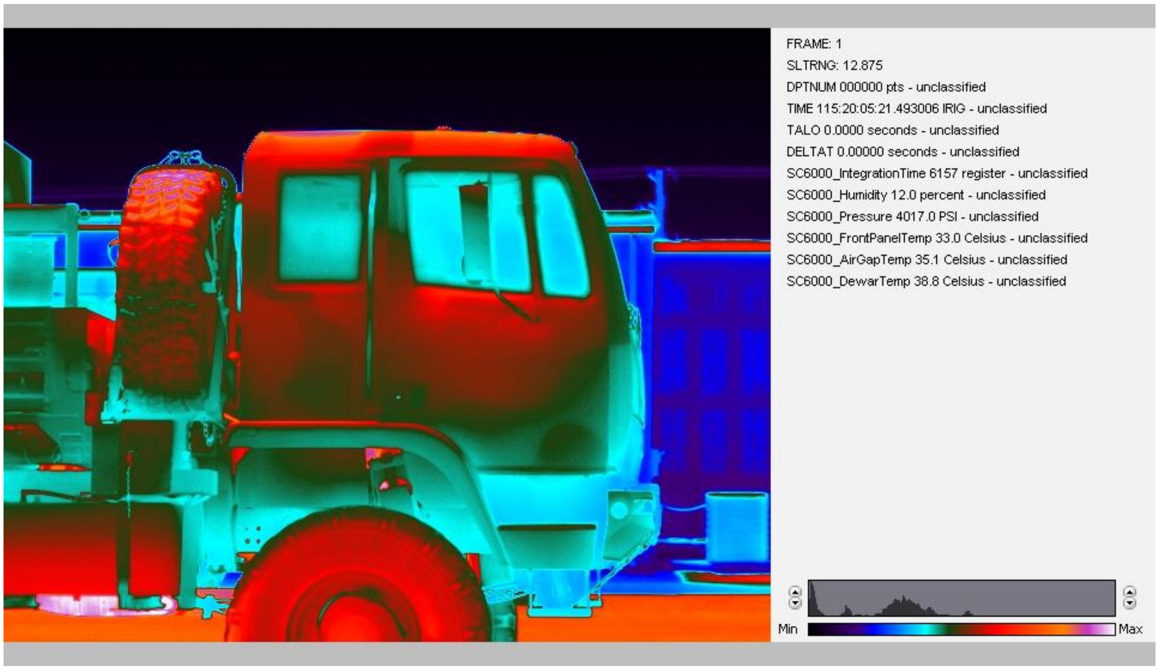

Figure 2. IR signature of FMTV side view

c. Use an IR camera to record the IR signature of the inside of the test truck, if possible.

d. Take digital photos of the installed instrumentation.

5.3 Ventilation with Temperature Measurements Testing.

a. Mechanical Ventilation Measurements with Truck Stationary.

(1) Determine the enclosure volume of the truck cab and the number of occupants safely allowed in the cab so the enclosure volume per person can be calculated. The enclosure volume per person determines the minimum amount of ventilation required. See reference MIL-STD-1472F, Paragraph 5.8.1.2, Ventilating, for further guidance.

(2) Measure the dimensions of each ventilation register inside the truck cab in order to calculate the **total area** of the opening. Record the position of each ventilation register within the truck cab, e.g., center of console.

(3) Position the grill so that it is perpendicular to the ventilation register to minimize the obstruction of the grill on the flow of air. Measure the dimensions of the grill visible in the ventilation register at this position and calculate the **grill area** that is blocking the air flow.

(4) When taking an air velocity measurement by hand of a ventilation register, either a handheld vane anemometer or handheld hot wire anemometer may be used. If a handheld vane anemometer is used the largest area it can measure is less than 25% of the vane diameter. If the ventilation register is larger than that, the ventilation register will need to be divided into equal

parts to be measured. To take a measurement using a handheld vane anemometer the anemometer is held as close to the ventilation register as possible without anything touching. The vane anemometer is kept in place for 10 to 15 seconds until a stable reading is obtained. Take three air velocity measurements at each ventilation register or segment. Also, record the time of the reading to cross reference the matching temperature from the stored data file.

(5) If a handheld hot wire anemometer is used follow the procedures outlined in Appendix C. Take three air velocity measurements at each ventilation register or segment. Also, record the time of the reading to cross reference the matching temperature from the stored data file.

(6) If the hot wire anemometers are installed in the ventilation registers, record the time, the location of the ventilation register, and condition of the trial so the matching temperatures can be located in the respective temperature data files.

(7) Record which of the air velocity measurements are outside fresh air.

(8) Record the ambient temperature outside the test truck cab.

(9) Take digital photos of the installed instrumentation and configuration of the vehicle.

b. Ventilation Measurements with Windows and Hatches Opened and Truck Moving.

(1) Determine the enclosure volume of the truck cab and the number of occupants safely allowed in the cab so the enclosure volume per person can be calculated. The enclosure volume per person determines the minimum amount of ventilation required. See reference MIL-STD-1472F, Paragraph 5.8.1.2, Ventilating, for further guidance.

(2) Measure the dimensions of the windows when they are opened to the maximum extent. Measure the dimensions of the opened hatch or hatches. Calculate the area of the openings.

(3) If handheld vane anemometer or hot wire anemometer readings are to be taken, divide the window opening and hatch openings into two (2) to three (3) inch-square, or five (5) to eight (8) centimeter-square, segments. A grid can be made using fishing line, string, or some thin material, to divide the windows or hatch openings into equal segments.

(4) With the blower off, the air conditioning off, and the vehicle moving at 10 mph (16 kph), take air velocity measurements of each segment using a handheld anemometer just inside the truck cab until all measurements are taken. Take three measurements at each segment of each window and each hatch. Repeat the procedure increasing the test truck speed by 10-mph (16-kph) increments until the maximum speed is attained and measurements are taken for all segments of windows and hatches at each incremented speed.

(5) If the grid in the windows and hatches is instrumented with hot wire anemometers, record the time, location, and condition of the trial so the anemometer readings and matching temperatures can be located in their respective data files.

(6) Take digital photos of the installed instrumentation and vehicle configuration.

c. Ventilation Measurements with Test Participants.

(1) Human Testing with Stationary Truck.

(a) Have a TC at the side of the head, waist, and feet of each test participant's seat.

(b) Take air velocity measurements with the vane anemometer at a distance of 2.5 times the vane diameter from the head, waist, and feet of each test participant in each set of conditions chosen in 4.4.c(1)(f). Adjust the vane anemometer so the maximum flow of air towards the participant's head, waist, and feet is obtained. Record the date, time, and location of each air velocity measurement in order to cross reference the temperature measurement in the appropriate temperature data files.

(c) Take digital photos of the installed instrumentation and vehicle configuration.

(2) Human Testing with Moving Truck.

(a) Administer a Before Ride Thermal Comfort Questionnaire found in Appendix A to all participants before the Human Testing with Moving Truck begins.

(b) Have a TC at the side of the head, waist, and feet of each participant's seat.

(c) Take air velocity measurements with a vane anemometer at a distance of 2.5 times the vane diameter from the head, waist, and feet of each test participant in each set of conditions chosen in 4.4.c(2)(d). Adjust the vane anemometer so the maximum flow of air towards the participant's head, waist, and feet is obtained. Record the date, time, and location of each air velocity measurement in order to cross reference the temperature measurement in the appropriate temperature data files.

(d) Take three vane anemometer measurements at each head, waist, and foot location of every crew position.

(e) Record the air turbulence, or lack of it, inside the cab by observing the movement of the ribbons at various locations.

(f) Take digital photos of the installed instrumentation and vehicle configuration.

(g) Administer an After Ride Thermal Comfort Questionnaire found in Appendix B to all participants after the Human Testing with Moving Truck is completed.

d. Thermal Comfort Performance Testing.

(1) Administer a Before Ride Thermal Comfort Questionnaire found in Appendix A to all participants before the Thermal Comfort Performance Testing begins.

(2) Have a TC at the side of the head, waist, and feet of each participant's seat.

(3) Operate the test truck during the hottest part of the day. Temperature data on the exterior and interior of the roof will be collected and used to determine the Solar Load.

(4) Record the air turbulence, or lack of it, inside the cab by observing the movement of the ribbons at various locations.

(5) Take digital photos of the installed instrumentation and vehicle configuration.

(6) Use an IR camera to record the IR signature of the outside of the test truck.

(7) Use an IR camera to record the IR signature of the inside of the test truck.

(8) Administer an After Ride Thermal Comfort Questionnaire found in Appendix B to all participants after the Thermal Comfort Performance Testing is completed.

(9) Before the ride begins administer the Before Ride Thermal Questionnaire to all the participants who are unfamiliar with the test truck. When the test ride is complete administer the After Ride Thermal Comfort Questionnaire to the same group.

6. PRESENTATION OF DATA.

6.1 Thermal Survey for Hot Spots.

Present hot spots identified by the handheld IR thermometer along with the corresponding temperatures obtained by using a surface TC. Also, present digital photos of these hot spots.

6.2 Heat Soak Test.

a. Calculate the Solar Load for each time slice of data by subtracting the exterior temperature ($T_{\text{Exterior Roof Cab}}$) of the cab roof from the corresponding interior temperature ($T_{\text{Interior Roof Cab}}$). Do this for each time slice of the entire Heat Soak test.

$$T_{\text{Interior Roof Cab}} - T_{\text{Exterior Roof Cab}} = \text{Solar Load for One Time Slice}$$

Plot temperature differences versus time (slices) to ensure the temperature differences are consistent. Examine the plot for any spikes, or anomalies. If there are no spikes, the plot is the Solar Load of each time slice for the entire Heat Soak test. If there are spikes, remove the temperature differences that are much smaller or larger than the adjacent differences. Plot this data which provides the Solar Load of each time slice for the entire Heat Soak test.

b. Plot each of the other data files for the Heat Soak test. Review the plots for the entire duration of the test. Remove any points that are much smaller or much larger than the adjacent data.

c. Plot cab interior WBGT, dry bulb, black globe, and the exterior mast dry bulb on the same plot, if possible. After reviewing all the other plots of data, present related temperature plots together on one plot where it is feasible. For instance, a grouping may be of temperatures on a "dog house" or temperatures on the console or temperatures at all the ventilation registers. Some plotted data may need to be presented by itself as in the humidity data and pyranometer data.

d. Present IR signature pictures of all exterior sides and interior, if possible, of the vehicle. Also, present digital photos of the test.

6.3 Ventilation with Temperature Measurements Testing.

a. Mechanical Ventilation Measurements with Truck Stationary.

(1) Calculate the enclosure volume per person for the test truck cab. If the enclosure volume is 150 feet ^{3} (4.25 meters ^{3}) or less per person, the minimum ventilation air is 30 feet ^{3} (0.85 meter ^{3}) per minute per person. If the enclosure volume is greater than 150 feet ^{3} (4.25 meters ^{3}) per person, see reference MIL-STD-1472F, Figure 35, to obtain the minimum ventilation air per minute person.

(2) To make it easier to compare ventilation register air flow results with the ventilation air criteria, multiply the minimum or the lower and upper ranges of the criteria by the number of occupants the test vehicle was designed to safely transport. The result is the total minimum or lower or upper ventilation air (air flow) in feet ^{3}, or meters ^{3}, per minute which can be easily compared with the total air flow obtained by adding the air flow of each ventilation register together for each trial.

(3) Subtract each ventilation register's **grill area** from the ventilation register's **total area**. This result will give the **unobstructed surface area** of the ventilation register through which air can flow.

(4) If the air velocity measurements were taken using a handheld vane anemometer or hot wire anemometer and the ventilation register was not subdivided, calculate the average of the three velocity measurements for that register. If a handheld vane anemometer or hot wire anemometer was used and the ventilation register was large and divided into segments, calculate the average of the three air velocity measurements for each segment of that register. Then calculate the average of the segment averages for that register to obtain the average air velocity for the ventilation register.

(5) If the air velocity measurements were taken by one or more hot wire anemometers that were installed at a ventilation register and instrumented to a data logger, plot the data to find any spikes in it. Remove any spike data that is much smaller or much larger than the adjacent data. Take an average of the consistent data of each instrumented anemometer for each trial. If a ventilation register has more than one anemometer instrumented to it, calculate the average of the averaged data of all the anemometers instrumented to it. This last average is the average air velocity measurement at a ventilation register.

(6) Multiply the average air velocity measurement for each register by the **unobstructed surface area** of the ventilation register. The result is the air flow for each ventilation register.

(7) For each trial, add the air flow of each different register together. This is the total air flow (ventilation) for the truck cab enclosure for that trial condition. Note which air velocity measurements were for outside fresh air.

(8) Plot the temperature data for each ventilation register. Remove any points that are much smaller or much larger than the adjacent data. Then obtain the temperature in each ventilation register's temperature data file, for the same documented time when the air velocity measurement was taken. Make note of the ventilation register location, time, and temperature.

(9) In tabular form, present the matrix conditions of each trial, the resulting air flow measurement and temperature for each ventilation register, and also the total air flow for each different register combined. Three columns can be added that indicate whether the criteria for the outside fresh air and the other two ventilation measurements were met or not. (If the temperature is not above 90°F (32°C), the ventilation requirement of 6.3.a(2)(b) need not be considered.) If any of these ventilation criteria is not met, it becomes a safety issue.

(10) The temperature range outside of the truck cab can be stated or presented as a plot in the narrative. Also, any other relevant temperature data can be included in the report. Before using values from a data file, plot the file and remove any points that are inconsistent.

(11) Present some of the digital photos that were taken for this test.

b. Ventilation Testing with Windows and Hatches Opened and Truck Moving.

(1) Reference in this document the criteria for minimum ventilation air cited in 6.3.a.(1), and for minimum outside (fresh) air cited in 6.3.a(2)(a), and air flow rates in temperatures above 90 °F (32°C) cited in 6.3.a.(2)(b).

(2) Calculate the enclosure volume per person for the test truck cab. If the enclosure volume is 150 feet ^{3} (4.25 meters ^{3}) or less per person, the minimum ventilation air is 30 feet ^{3} (0.85 meter ^{3}) per minute per person. If the enclosure volume is greater than 150 feet ^{3} (4.25 meters ^{3}) per person, see reference MIL-STD-1472F, Figure 35, to obtain the minimum ventilation air per minute person.

(3) To make it easier to compare window and hatch air flow results with the ventilation air criteria, multiply the minimum or the lower and upper ranges of the criteria by the number of occupants the test vehicle was designed to safely transport. The result is the total minimum or lower or upper ventilation air (air flow) in feet ^{3}, or meters ^{3}, per minute which can be easily compared with the total air flow obtained by adding the air flow of each window or hatch together for each trial.

(4) If a handheld vane anemometer or handheld hot wire anemometer is used, for each trial add together the air velocity measurement for each segment of a window or a hatch and divide by the total number of segments to obtain the average air velocity for each trial for each window or hatch. Take the average of all three averages for each trial at each window and each hatch. The result is the average air velocity of a window or hatch for each trial. If hot wire anemometers are instrumented in the windows or hatches, plot the data for each anemometer. Remove any spike data that is much smaller or larger than the adjacent data. Take the average of the data for each anemometer for each trial. Calculate the average of the averaged data for all the anemometers for each trial connected to each window or hatch. The result is the average air velocity of a window or hatch for each trial.

(5) Multiply the average air velocity of a window or hatch for each trial by its corresponding area to get its air flow. Add the air flow of each opened window and hatch together for each trial to obtain the total air flow for the truck cab enclosure for each trial.

(6) Plot the temperature data. Remove any points that are much smaller or much larger than the adjacent data. Locate the temperature in each temperature data file for each window or hatch, at the documented time the air velocity measurement was taken. Make note of the window or hatch location, time, and temperature.

(7) In tabular form, present each trial of the matrix, the resulting air flow measurement for each opened window and hatch. Also, present the resultant total air flow of all the windows and hatches combined for this trial. Three additional columns can be added that state whether the ventilation criteria for this test were met or not. If they were not, they become safety issues.

(8) The overall range of the temperature at each window or hatch while it was measured can be stated in the narrative or included in a plot.

(9) The temperature range outside of the truck cab can be stated or presented as a plot in the narrative. Also, any other relevant temperature data can be included in the report. Before using values from a data file, plot the file and remove any points that are inconsistent.

(10) Digital photos of the test can be included.

c. Ventilation Testing with Test Participants.

(1) Human Testing with Stationary Truck.

(a) Find the temperature in the temperature data file that corresponds to the time and location (head, waist, or feet of each test participant's location) of the air velocity measurement.

(b) Present in tabular form the air velocity and temperature at the head, waist, and feet of each test participant for the worst, best, and medium set of test conditions. Include an additional column that states whether the criterion for the air velocity at the head location of each test participant was met or not.

(c) The temperature range outside of the truck cab can be stated or presented as a plot in the narrative. Also, any other relevant temperature data can be included in the report. Before using values from a data file, plot the file and remove any points that are inconsistent (anomalies).

(d) Present digital photos of the test.

(2) Human Testing with Moving Truck.

(a) Find the temperature in the temperature data file that corresponds to the time and location (head, waist, or feet of each test participant's location) of the air velocity measurement.

(b) Present any air turbulence or lack of air movement that was observed from the movement of the ribbons attached inside the truck cab.

(c) Present in tabular form the air velocity and temperature at the head, waist, and feet of each test participant for the worst, best, and medium set of test conditions. Include an additional column that states whether the air velocity at the head location of each test participant was met or not. NOTE: a negative air velocity indicates the air is not flowing towards the test participant and needs to be reported as such.

(d) The temperature range outside of the truck cab can be stated or presented as a plot in the narrative. Also, any other relevant temperature data can be included in the report. Before using values from a data file, plot the file and remove any points that are inconsistent.

(e) Compile results including comments from the Before Ride and After Ride Thermal Comfort Questionnaires of all the test participants. The results include the number of times each response was chosen for each question. Present in tabular form, questions, responses and comments from each questionnaire. Copies of individual questionnaires without names may be included in the appendix of the test report.

d. Thermal Comfort Performance Testing.

(1) Calculate the Solar Load for each time slice of data as described in 6.2.a.

(2) Handle each of the other data files for the Thermal Comfort Performance Testing as described in 6.2.b.

(3) Plot and review cab interior WBGT, dry bulb, black globe, and the exterior mast dry bulb as described in 6.2.c.

(4) Plot the temperature data at the head, waist, and feet of each test participant. Examine the spikes in the plots and remove any points that are much smaller or larger than the adjacent temperatures.

(5) Combine the plots of the temperatures at the head, waist and feet of each participant onto one plot. Present a combined temperature plot for each test participant.

(6) Document any turbulence or lack of air movement that can be observed from the movement of the ribbons attached inside the truck cab. Include this information in the test report.

(7) Present IR signature pictures of all exterior sides and interior, if possible, of the vehicle. Also, present digital photos of the test.

(8) Compile results of questionnaires as described in 6.3.c.(2)(e).

APPENDIX A. BEFORE RIDE THERMAL COMFORT QUESTIONNAIRE

NOTE: The following is an example of a before ride questionnaire. It can be modified to suit the testing that is being performed.

Please complete the following questionnaire before beginning the Thermal Comfort Test.

1. ID or Name ___________________________ Date ___________________________

2. Name of Test _____________________________

3. How are you feeling today? ____

4. Did you sleep well last night? ____

5. When was the last meal that you ate? ______________________________________

6. a. How much liquids have you had so far today? ______________________________

   b. What kind of liquids have you drunk? _______________________________________

7. a. Have you ever experienced any heat stress related disorders like heat cramps, dehydration, heat exhaustion, and heat stroke? YES _____ NO _____

   b. Which heat disorders and how long ago? ____________________________________

   ____

Thank you for completing this questionnaire.

APPENDIX B. AFTER RIDE THERMAL COMFORT QUESTIONNAIRE

NOTE

This is only a sample questionnaire designed to guide you in the development of a questionnaire relevant to the truck cab you are testing. This data can be compared to the temperatures recorded during the same time periods for validation of the comments from the test participants.

The following questionnaire is provided to allow you to comment on the comfort of the truck cab you rode in as an operator or passenger. It specifically requests your subjective evaluations and comments upon the thermal environment and its effects on your comfort during the ride. The questionnaire also seeks your comments and observations on the ventilation within the cab and its effects on your comfort. Some of the questions will be time oriented, therefore, be very conscious of time as you ride the courses. The questionnaire uses a 7-point rating scale. You are requested to circle the number that most closely represents your experience with the question. Additionally, please comment upon your experiences both positive and negative. Your comments are very valuable to the investigators and we sincerely appreciate your efforts and responses.

THERMAL COMFORT QUESTIONNAIRE

1. ID or Name ____________________ Date _________________________

2. Name of Test __________________________

3. What position did you occupy within the vehicle cab during the test ride? Please place an "X" on the line identifying your position.

_____ Driver _____ Right Front Passenger

_____ Left Rear Passenger _____ Middle Rear Passenger _____ Right Rear Passenger

4. When you entered the vehicle, the outside temperature was:

7	6	5	4	3	2	1
Extremely Hot	Very Hot	Hot	Neither Hot nor Cold	Cold	Very Cold	Extremely Cold

Comments____
____

5. When you entered the vehicle, the inside temperature was:

7	6	5	4	3	2	1
Extremely Hot	Very Hot	Hot	Neither Hot nor Cold	Cold	Very Cold	Extremely Cold

Comments____
____

6. The flow of the air across your body was:

7	6	5	4	3	2	1
Extremely Adequate	Very Adequate	Adequate	Neutral	Poor	Very Poor	Extremely Poor

Comments____
____

7. After 15 minutes of operation the cab temperature:

7	6	5	4	3	2	1
Decreased Rapidly	Decreased Slowly	Decreased	No Change	Increased	Increased Slowly	Increased Rapidly

Comments____
____

8. Your comfort level after 15 minutes of riding was:

7____ Extremely Comfortable
6____ Very Comfortable
5____ Comfortable
4____ Neutral
3____ Uncomfortable
2____ Very Uncomfortable
1____ Extremely Uncomfortable

Comments____
____

9. As the vehicle speed increased, the air flow across your body:

7	6	5	4	3	2	1
Decreased Rapidly	Decreased Slowly	Decreased	No Change	Increased	Increased Slowly	Increased Rapidly

Comments____
____

10. After 30 minutes of riding, the flow of the air across your body was:

7	6	5	4	3	2	1
Extremely Adequate	Very Adequate	Adequate	Neutral	Poor	Very Poor	Extremely Poor

Comments____
____

11. After 30 minutes of riding the temperature inside the vehicle was:

7	6	5	4	3	2	1
Extremely Hot	Very Hot	Hot	Neither Hot nor Cold	Cold	Very Cold	Extremely Cold

Comments____
____

12. Your comfort level after 30 minutes of riding was:

7____ Extremely Comfortable
6____ Very Comfortable
5____ Comfortable
4____ Neutral
3____ Uncomfortable
2____ Very Uncomfortable
1____ Extremely Uncomfortable

Comments____
____

13. Your comfort level after 1 hour of riding was:

7____ Extremely Comfortable
6____ Very Comfortable
5____ Comfortable
4____ Neutral
3____ Uncomfortable
2____ Very Uncomfortable
1____ Extremely Uncomfortable

Comments____
____

14. After 1 hour of riding the temperature at your position was:

7	6	5	4	3	2	1
Extremely Hot	Very Hot	Hot	Neither Hot nor Cold	Cold	Very Cold	Extremely Cold

Comments____
____

15. After 1 hour of riding, the flow of the air across your body was:

7	6	5	4	3	2	1
Extremely Adequate	Very Adequate	Adequate	Neutral	Poor	Very Poor	Extremely Poor

Comments____

____

16. Your comfort level after 2 hours of riding was:

7____ Extremely Comfortable
6____ Very Comfortable
5____ Comfortable
4____ Neutral
3____ Uncomfortable
2____ Very Uncomfortable
1____ Extremely Uncomfortable

Comments____

____

17. After 2 hours of riding the temperature at your position was:

7	6	5	4	3	2	1
Extremely Hot	Very Hot	Hot	Neither Hot nor Cold	Cold	Very Cold	Extremely Cold

Comments____

____

18. After 2 hours of riding, the flow of the air across your body was:

7	6	5	4	3	2	1
Extremely Adequate	Very Adequate	Adequate	Neutral	Poor	Very Poor	Extremely Poor

Comments____

____

19. The effect of the terrain on the temperature was:

7	6	5	4	3	2	1
Extremely Large	Very Large	Large	Moderate	Little	Very Little	No Effect

Comments____

____

20. Overall the temperature inside the vehicle at your position was:

7	6	5	4	3	2	1
Extremely Hot	Very Hot	Hot	Neither Hot nor Cold	Cold	Very Cold	Extremely Cold

Comments____
____

21. Overall the Ventilation inside the cab at your position was:

7	6	5	4	3	2	1
Extremely Adequate	Very Adequate	Adequate	Neutral	Poor	Very Poor	Extremely Poor

Comments____
____

22. Overall, the comfort of the vehicle at your position was:

7____ Extremely Comfortable
6____ Very Comfortable
5____ Comfortable
4____ Neutral
3____ Uncomfortable
2____ Very Uncomfortable
1____ Extremely Uncomfortable

Comments____
____

23. What could be done to improve the overall comfort of the vehicle?____
____

24. This vehicle compared to other vehicles of similar design was:

Better________ Worse_________ About the same________.

APPENDIX C. MEASURING AIR FLOW
(Copied from Omega.com on 31 May 2007)

MEASURING AIR FLOW
in Ducts, Pipes, Hoods and Stacks

Anemometers have traditionally been employed for air duct balancing. This cumbersome task requires performing a traverse of the opening, measuring and manually recording the velocity at numerous points, calculating the mean velocity, and then multiplying the mean velocity by the cross-sectional area of the duct or opening to obtain the total volumetric flowrate measurement in cubic feet per minute (CFM) flow rate.

With the newest microprocessor-based anemometers, up to a thousand data points can be stored in the memory for mean velocity calculation. Some units can even multiply the mean velocity by the cross-sectional area to give the readout in CFM. These capabilities provide tremendous new convenience for the HVAC professional.

TOTAL FLOW RATES

Total flowrate through an opening (Q in SCFM) is determined by the following relationship:

$Q = \overline{V}A$, where:

$\overline{V}$ = average velocity in SFPM (standard feet per minute), and
A = cross-sectional area of duct or pipe (in ft²).

To determine the average velocity $\overline{V}$, divide the opening into a number of equal areas. Take a velocity reading at the center of each area and numerically average the results. If the velocity profile is relatively flat, only a few equal areas are needed. If the profile is non-uniform, several equal areas should be used. Generally, it is a good idea to make a rapid traverse across the duct in two dimensions to determine the uniformity of the air velocity. If the velocity is not constant at one measuring point, use the mean velocity between the upper and lower readings. Generally, the velocity profile is more uniform on suction openings than on supply openings. If a supply opening is covered by a grille, the probe should be placed about 1" in front of the grill to obtain the average velocity reading as above.

If information is given on the coefficient of discharge for a specific grille, the probe should be placed against the grille and centered over the open areas in the grille.
Choose several grille openings through which to obtain an average air velocity. In this case, the total flow is:

$Q = KA\overline{V}$, where:

K = the given coefficient discharge
A = the area of the grille as specified by the manufacturer

If a return or suction opening is covered by a grille and it is necessary to compute the total flow into the opening, take a number of readings at the centers of equal areas, as in the case where there is no grille, and determine the average velocity. The probe should be placed in the plane of the opening and close to the grille. The flowrate can be computed fairly accurately with the following equation:

$Q = FA\overline{V}$, where:

F = application factor (see table below)

A = designated area in square feet

Grille Type	Application Factor, F	Designated Area
None	1.00	Full duct area
Square Punched	0.88	Free (daylight) area
Bar	0.78	Core Area
Steel Strip	0.73	Core Area

For applications requiring higher accuracy, it is suggested that a duct extension be used having a length at least as great as the largest dimension of the grille. This duct extension is placed against the grille, and the procedures for an open grille are followed to compute flowrate. For highest accuracy, a smoothly tapered flow nozzle should be placed over the supply grille. In this case, the velocity profile at the exit jet of such a nozzle is very flat.

Duct Traversing

The log-linear method provides high accuracy (±3%) in flow totalization by taking into consideration the effect of friction along the walls of a duct. For round ducts, the three-diameter, six-point method is the preferred traverse. If the three-diameter method cannot be used (because of inaccessibility), then the two-diameter method is acceptable. This method consists of taking two sets of ten readings, 90° apart.

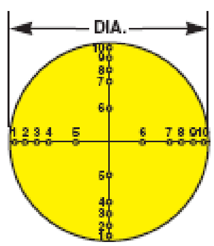

Figure 1. Log linear-traverse for round ducts, three-diameter approach.

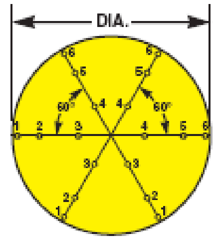

Figure 2. Log-linear traverse for round ducts, two-diameter approach.

With rectangular ducts, the following procedure is recommended:

1. The table below indicates that any rectangular duct dimension less than 30" requires five traverse lines on that side. Thus, a 28 x 20" duct will require 25 readings, because each side needs five traverse lines. A 38 x 20" duct will require 35 readings (seven traverse lines on the 38" side and five on the 20" side).

Duct Side Dimension	Number of Traverse Lines
< 30"	5
>30" but < 36"	6
>36"	7

2. The minimum number of readings should be 25.
3. The points where the readings are to be taken should be located at the intersection of the traverse lines as shown (as proportions of the traverse measurement) below:

No. of Traverse Lines		
5	6	7
0.074	0.061	0.053
0.288	0.235	0.203
0.500	0.437	0.366
0.712	0.563	0.500
0.926	0.765	0.634
	0.939	0.797
		0.947

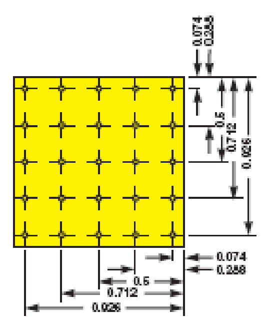

Figure 3. Example of a 25-point log linear-traverse for rectangular ducts.

APPENDIX D. REFERENCES

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2. TOP 2-2-508, Automotive Safety and Heat Evaluation, 24 November 1982.

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5. MIL-STD-1472F, Department of Defense Design Criteria Standard Human Engineering, 05 December 2003.

6. USARIEM Technical Note 95-1, Sustaining Soldier Health and Performance in Southwest Asia: Guidance for Small Unit Leaders, October 1994.

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FOR INFORMATION ONLY

a. TOP 1-2-610, Human Factors Engineering Part 1, Test Procedures, 15 May 1990.

b. Vehicle Thermal Management, Alec C. Alkidas, Editor, Society of Automotive Engineers, Inc., 1994.

c. Environmental Ergonomics, Igor B Mekjavic, Eric W. Bannister, and James B. Morrison, Editors, Taylor and Francis, Philadelphia, PA, 1988.

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 (CSTE-DTC-TM-B), US Army Developmental Test Command, 314 Longs Corner Road Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: Combat and Automotive Systems Division (CSTE-DTC-YP-YT-CA), US Army Yuma Proving Ground, Yuma Test Center, 301 C. Street, Yuma, Arizona 85365-9498Your Test Center Address. 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.