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14. ABSTRACT
This TOP prescribes procedures for evaluating the durability of mobile equipment while being subjected to accelerated corrosion. Major factors to be considered when evaluating the effects of corrosion on mobile equipment include the intended operational environment, Preventive Maintenance Checks and Services (PMCS), and corrosion monitoring methodology. Events used to accelerate corrosion and its effects include salt mist, salt splash, grit splash, high heat/high humidity, and shock and vibration input from various terrain.

15. SUBJECT TERMS
scribe PMCS corrosion penetration salt mist salt splash grit trough mission profile event cycle phase corrosion stages

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 01-1-065 15 October 2013
DTIC AD No.

ACCELERATED CORROSION DURABILITY

			Page
Paragraph	1.	SCOPE	2
	1.1	Purpose	2
	1.2	Limitations	3
	2.	FACILITIES AND INSTRUMENTATION	3
	2.1	Facilities and Test Courses	3
	2.2	Test Instrumentation	5
	2.3	Specialized Equipment	6
	3.	REQUIRED TEST CONDITIONS	6
	3.1	Preparation for Test	6
	3.2	Test Controls	6
	3.3	Restrictions	7
	4.	TEST PROCEDURES	7
	4.1	General	7
	4.2	Test Item Characterization	7
	4.3	Initial Inspection	7
	4.4	Fresh Water Splash Testing	7
	4.5	Test Monitoring Mass Loss Coupons and Scribes	8
	4.6	Test Events	8
	4.7	Final Inspection	12
	5.	DATA REQUIRED	12
	5.1	General	12
	5.2	Test Item Characterization	12
	5.3	Initial Inspection	12
	5.4	Fresh Water Splash Testing	13
	5.5	Test Monitoring Coupons and Scribes	13
	5.6	Test Events	13
	5.7	Final Inspection	13
	6.	PRESENTATION OF DATA	14
	6.1	General	14
	6.2	Test Item Characterization	14
	6.3	Initial Inspection	14
	6.4	Fresh Water Splash Testing	14
	6.5	Test Monitoring Coupons and Scribes	14
	6.6	Test Events	15
	6.7	Final Inspection	18

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APPENDIX	A.	CORROSION FACILITY DESCRIPTION/PROCEDURES	A-1
	B.	BACKGROUND INFORMATION AND TEST METHODOLOGY	B-1
	C.	EVALUATION TECHNIQUES	C-1
	D.	EQUIPMENT MAINTENANCE	D-1
	E.	ABBREVIATIONS	E-1
	F.	REFERENCES	F-1
	G.	APPROVAL AUTHORITY	G-1

1. SCOPE.

This Test Operations Procedure (TOP) provides standardized testing for evaluating the effects of corrosion on mobile equipment durability.

1.1 Purpose.

a. Accelerated corrosion testing is combined with durability testing to improve our ability to evaluate the interaction between corrosion and physical stresses that act upon a piece of equipment. The interaction of these stresses very often causes different service failures than might be revealed by either corrosion or durability testing alone. Due to the nature of military activities, the actual service environment of specific equipment can never be accurately forecasted. In times of crisis, equipment can be called to any environment in the world for an extended period of time. Equipment will need to operate effectively within all environments in order to ensure that no failures occur that can jeopardize lives. In times of decreasing acquisition and maintenance budgets, it is important that weapon systems are acquired with an appreciation of the total life cycle cost of the system. Systems built with materials that have exceptional corrosion performance capabilities may have an enormous acquisition cost. Other materials that have been historically used may require excessive maintenance when placed in some of the severe environments that military equipment experiences. A compromise must be made between performance and maintenance requirements to obtain the best total life cycle cost benefit from selected system materials.

b. The Accelerated Corrosion Durability Test (ACDT) will generate the appropriate information to determine what corrosion performance and maintenance requirements may be expected for equipment in the target environment. It will not likely be cost effective to design all equipment for zero corrosion in the target environment. However, given an expectation of the performance and service life requirements, ACDT results can be used to identify areas that do not provide the desired level of material performance (i.e., experience unacceptable levels of corrosion).

c. Many different environmental and physical stresses act upon equipment during its life. The stresses affect metals, plastics, coatings, greases, ceramics, etc., in different ways. There are also numerous types of corrosion that act upon a vehicle in different circumstances and at different rates. The test procedure is set up according to commercial experience to best simulate corrosion phenomena that limit the useful life of equipment. Specifically, this includes identifying the ability of the paint system to resist any types of defects, the identification of any crevice corrosion that may lead to rust bleed-out and rust staining, and identifying any corrosion that causes failure of any working components. Corrosion test events are designed to:

(1) Apply corrosive contaminants that are likely to be present in service environments.

(2) Expose the contaminants to all surfaces of the equipment that may occur during its expected use.

(3) Create an environment where the corrosion caused by these contaminants will occur at an accelerated rate.

d. Applying contaminants and working them onto/into all appropriate surfaces occurs simultaneously throughout the ACDT events. The corrosion mechanisms are accelerated through the use of an environmental chamber that provides a high temperature, high humidity environment. The chamber test durations are used to control the severity of the corrosion on the test items.

1.2 Limitations.

This TOP describes testing to assess the effects of corrosion on mobile equipment durability based on the expected mission profile, equipment maintenance and service schedules, and operating environment. It is very important that these factors are accurately determined since they greatly impact the validity of the test results. It is necessary to customize this test procedure based on these factors for each unique test item while following this procedure as a general guide. This procedure is focused on metallic corrosion and does not accelerate Microbial Induced Corrosion (MIC) or degradation of non-metallic materials such as plastics or rubbers due to solar exposure or other causes of degradation besides what is identified in this procedure.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities and Test Courses.

Facility	Requirement
Salt Mist Booth	An enclosed work bay. Spray nozzles are positioned across the sides and top of the facility to provide full salt spray application to all exterior surfaces on the top, sides, front, and back of the vehicle.

Facility (cont'd)	Requirement (cont'd)
Salt Splash Trough	A trough approximately 23 meters (m) (75 feet (ft)) long. The depth of the salt solution should be maintained at 5 centimeters (cm) (2 inches (in.)). The intent of the salt splash is to ensure a variety of wetting scenarios that uniformly, yet realistically, wet the underside of the vehicle.
Grit Trough	A trough approximately 23 m (75 ft) long with sloping entrance and exits on each end. The grit depth should be maintained at approximately 10 to 20 cm (4 to 8 in.). Bumps can be added to the trough to induce body twisting and flexing.
Fording Basin	A basin capable of fording the test item at a depth of up to 152 cm (60 in.).
Primary Road	An evenly paved surface capable of allowing continuous travel of the vehicle at 72 kilometers per hour (km/hr) (45 miles per hour (mph)). The oval-shaped facility consists of two straight sections, each 0.40 kilometer km) (0.25 mile (mi)) long, joined at each end by 0.40-km (0.25-mi) sections of regular curvature to form an oval totaling 1.6 km (1.0 mi) in length.
Secondary Road - Gravel	An improved gravel road course. The course is a loop of about 3.4 km (2.1 mi) with left and right curves.
Cross-Country Road/Trail	Cross-country roads simulated using a rolling hill course. The course was designed to provide short, closely spaced grades with 30-cm (12-in.) bumps to provide suspension input. The surface consists of crushed stone compacted with stone dust binder. The course is 0.6 km (0.4 mi) in length and contains a paved turn-around section at either end. Trails consist of 1.1 km (0.7 mi) of a Belgian Block course. The facility is paved with unevenly laid granite blocks forming an undulating surface.

Facility (cont'd)	Requirement (cont'd)
Frame Twister	The road is divided in half and creates two separate series of hills (waves) on either side. These waves are 4.3 m (14.0 ft) from peak to valley and are 180 degrees out of phase (i.e., when one wheel is at a peak the wheel on the opposite side of the vehicle is in a valley). At each peak's maximum point, the wheel is raised 0.6 m (2.0 ft) above the average height. At each valley's minimum point, the wheel is lowered 0.6 m (2.0 ft) below the average height. The total length of the course is 135 m (443 ft).
Humidity Chamber	The humidity chamber has a working area sufficient to hold the test item being tested. Humidity and temperature transducers are used to control the specified conditions. Circulation fans are used to provide a moderate flow of the high humidity air throughout the chamber.
Wash Bay	Washing shall consist of low-pressure, high volume fresh water.
Ambient Storage Bay	A facility such as a maintenance bay that is protected from the environment.

2.2 Test Instrumentation.

Devices for Measuring	Permissible Measurement Uncertainty[a]
Coupon mass	0.1 (milligram (mg))
Conductivity (relating to salinity)	1% (milliSiemens per centimeter (mS/cm))
Film thickness	2.5 (micrometers (µm))
Meteorological data:	
Ambient temperature	1 °C
Humidity	3%
Dew point	1 °C
Wind speed	5%

NOTE a: The permissible measurement uncertainty is the two-standard deviation value for normally distributed instrumentation calibration data. Thus 95 percent of all instrumentation calibration data readings will fall within two standard deviations from the known calibration value.

2.3 Specialized Equipment.

Specialized equipment and instrumentation required for vehicle preparation, test course set-up, and test observation are as follows:

a. Meteorological measurement equipment.

b. Coupon scale (analytical balance).

c. Conductivity meter.

d. Dry Film thickness gauge.

e. Digital camera.

f. Glass bead blaster.

g. Large solution mixing tanks.

3. REQUIRED TEST CONDITIONS.

3.1 Preparation for Test.

a. Review all instructional material issued with the test item by the manufacturer, contractor, or government, as well as reports of previous similar tests on the same types of equipment.

b. Select the applicable test procedures to be used based on the requirements documents and purpose of the test.

c. Prepare data collection sheets to record all pre-test information, conditions of test, test results, observations, and measurements that would be valuable in analysis and assessment.

d. Ensure that all test personnel are familiar with the required technical and operational characteristics of the item and with the required test procedures.

3.2 Test Controls.

Prior to the initiation of testing, ensure that:

a. The equipment has been prepared and equipped in accordance with standard use and/or within the procedures presented in the test plan.

b. The equipment has been inspected and serviced in accordance with applicable manuals.

3.3 Restrictions.

Local safety and operational procedures will be carefully followed.

4. TEST PROCEDURES.

4.1 General.

TOPs 02-2-505[1**] and 02-2-506[2] are to be used in conjunction with these procedures.

4.2 Test Item Characterization.

Test item identification, characteristic photographs, and basic measurements including overall dimensions and weight distributions shall be recorded.

4.3 Initial Inspection.

Identify any deficiencies with the test item including loose or missing hardware, nonfunctional components, existing corrosion, damage from shipment, or any kind of non-compliance with manufacturer specifications. All discrepancies will be documented with photos and Test Incident Reports (TIRs). Repairs may or may not be made to the deficiencies that could have an effect on corrosion performance. Corrosion-related TIRs will be organized according to the test item sub assembly groups. This will reduce the number of TIRs generated and allow for ease of assigning corrosion stages to affected parts or components during the test. Film thickness measurements will be made on exterior surface areas of the test item to document coating thickness. The number, location, and type of thickness measurements are tailored to the test item and the data required.

4.4 Fresh Water Splash Testing.

This test is conducted prior to the start of the accelerated corrosion test events. The test item is driven through the splash trough, filled only with fresh water to the same depth that will be used during the test. The test item will be operated at a minimum of three different road speeds, up to the maximum safe speed in which there is no loss of vehicle control. These speeds will be used for splash trough operations during the corrosion test. After each run through the trough, a visual observation will be made to determine the area of the undercarriage covered by the road splash. The area of the undercarriage that is affected most severely by the road splash will be the

** Superscript numbers correspond to Appendix F, References.

location of the mass loss coupon rack used for tracking the amount of corrosion exposure for this area of the test item during the test.

4.5 Test Monitoring Mass Loss Coupons and Scribes.

Racks of test monitoring coupons shall be installed so that corrosion can be monitored in boldly exposed, semi-exposed, and protected areas of the test item. The coupons are used to track the corrosion rate during the test. More importantly, they provide feedback, allowing adjustment of the test variables so that the target corrosion is achieved. The size of the coupon racks depends on the duration of the test and the amount of data needed for assessments. Coupon placement will be determined following the fresh water splash testing (paragraph 4.4). Typical locations for vehicles include the roof of the cab, beneath the cab, behind the front passenger wheel, a semi-protected area on the side of the vehicle, and other areas of interest.

4.5.1 Mass Loss Coupons.

Mass loss coupons are used to track the amount of corrosion experienced by the test item throughout the test and to determine the number of humidity chamber events required to accomplish the desired corrosion rate. Mass loss coupons are fabricated from 1008 steel and measure 2.54 cm x 5.1 cm x 0.32 cm (1 in. x 2 in. x 0.125 in.) with a centered 0.67-cm (0.265-in.) hole used for mounting. Mounting procedures are presented in Appendix C. For evaluating the cumulative corrosion every other test year, the number of coupons installed will be equal to the number of test years plus two. For example, a 22 test year corrosion assessment requires a total of 24 coupons installed on each rack allowing for duplicate pairs to be removed at each evaluation (a total of 12 cumulative evaluations will be performed, including test year 1). Mass loss coupons will be removed at test years 1, 2, 4, 6,…, 20, and 22. The coupons shall be handled with gloves, cleaned with a solvent, such as acetone, and the initial mass of each coupon shall be recorded prior to installation on a rack. After removal, all corrosion on the coupons will be removed by glass bead blasting or another method that is minimally abrasive to the substrate. The coupons masses will be measured and the mass loss due to corrosion will be recorded. In addition to the cumulative evaluations, the outer most coupons on each rack will be removed and replaced with new coupons at the end of every test year to monitor the incremental corrosion. These mass loss measurements are used to monitor the severity of corrosion throughout the evaluation.

4.5.2 Scribes.

Scribes may be made on various surfaces of the test item. These scribes are meant to test the coating adhesion properties along with its resistance to underfilm cutback. Scribes will consist of one horizontal and one vertical line, at each location, which will penetrate through the entire coating system to the base metal. The lines will measure 5.1 cm (2.0 in.) in length and will not intersect at any point. Scribes will be made using a scribe tool. Scribes are typically made on larger surface areas of the test item and aren't intended to evaluate specific components.

4.6 Test Events.

Corrosion test events are either driving events or non-driving events. A description of the test events and facilities are provided in Appendix A. The structure of the ACDT is described below.

a. An event refers to the lowest level of vehicle driving activity. Each individual corrosion or durability input is considered to be an event.

b. A cycle refers to the group of events that are completed in a work day. The sequence of events in Table 1 is a sample cycle. Cycles can be tailored for the mission profile of specific equipment and desired target corrosion rates.

TABLE 1. SAMPLE TEST CYCLE

LAPS[a]	EVENT[b,c]	km	mi
1	Grit Trough	--	--
3	Secondary Roads (Gravel Road)	10.1	6.3
1	Salt Splash/Mist	--	--
3	Secondary Roads (Gravel Road)	10.1	6.3
1	Grit Trough	--	--
5	Trails (Belgian Block) Secondary (Access to Trails)	5.6 3.2	3.5 2.0
1	Salt Splash/Mist	--	--
5	Primary Roads (High Speed Test Track)	8.0	5.0
1	Grit Trough	--	--
3	Cross Country (Rolling Hills) Secondary (Access to Cross Country)	3.9 2.7	2.4 1.7
1	Salt Splash/Mist	--	--
5	Trails (Belgian Block) Secondary (Access to Trails)	5.6 3.2	3.5 2.0
1	Grit Trough	--	--
4	Primary Roads (High Speed Test Track)	6.4	4.0
1	Salt Splash/Mist	--	--
7	Cross Country (Rolling Hills) Secondary (Access to Cross Country)	9.0 2.7	5.6 1.7
1	Grit Trough	--	--
3	Secondary Roads (Gravel Road)	10.1	6.3
1	Salt Splash/Mist	--	--
5	Trails (Belgian Block) Secondary (Access to Trails)	5.6 3.2	3.5 2.0
1	Grit Trough	--	--
3	Cross Country (Rolling Hills) Secondary (Access to Cross Country)	3.9 2.7	2.4 1.7
1	Salt Splash/Mist	--	--
4	Primary Roads (High Speed Test Track)	6.4	4.0

NOTES: a. Number of laps and subsequent mileage is based on the mission profile of the test item.

b. The frame twister will be traversed after the 2nd and final phases.

c. Fording events (frequency and depth) will be conducted in compliance with the expected mission profile of the test item. Fording is typically completed once at the beginning and middle of each test year.

c. A test year is composed of 8 cycles. Background information and methodologies are further discussed in Appendix B.

4.6.1 Driving Test Events.

Several different test events are included in the accelerated corrosion test. Each event is a corrosion and/or durability input. The events are combined into a daily driving cycle as the sample shows in Table 1. Eight of these cycles, along with the humidity chamber events, determine the target corrosion rates for one phase or test year. Typically, 4 to 8 splash events and 6 to 8 mist and grit events are completed per cycle depending on target corrosion rates. Operating speeds are based on the mission profile of the vehicle and/or determined by conducting a jury ride. A jury ride is a pretest event conducted by members of the test IPT that determines reasonable durability inputs usually based on vehicle speed over terrain.

4.6.2 Non-Driving Test Events.

a. Post Test Year Inspection. At the end of each test year (8 cycles), an inspection will be accomplished to document the corrosion observed. TIRs will be generated and the test item condition will be documented with photographs. Components experiencing corrosion will be identified and the corrosion will be classified by stage. Appendix C provides detailed information on corrosion evaluations. Any failed components shall be removed and replaced as necessary to ensure that the vehicle is fully operational. The failed parts will be evaluated to determine the cause of failure. Critical systems will be exercised to validate functionality. This is to ensure that they continue to be operational and to incorporate the effects of accumulated grit, debris, and corrosion.

b. Humidity Chamber. Subsequent to each driving cycle, the vehicle will either be positioned in a humidity chamber to accelerate corrosion or be positioned in ambient storage to allow natural corrosion to take place. The humidity chamber will be used, as necessary, to achieve the target corrosion rates and is dependent upon the ambient environmental conditions. Test solutions are stored in ambient environmental conditions and although the temperature variance of the solutions have some effect on the corrosion rate, it is compensated by the number of humidity events that are performed. Table 2 is an estimate of the number of humidity events needed to achieve the target rates based on the time of year for average expected weather conditions for Aberdeen Proving Ground, MD. The actual number of humidity events per test year will be adjusted based on actual coupon corrosion rates. The number of humidity events needed is dependent upon the desired corrosion rates and the ambient weather at the location of the test.

TABLE 2. MONTHLY ESTIMATED HUMIDITY EVENTS FOR ABERDEEN PROVING GROUND, MD

MONTH OF THE YEAR	TARGET NUMBER OF EVENTS PER TEST YEAR
January	6
February	6
March	6
April	5
May	5
June	4
July	4
August	3
September	3
October	5
November	6
December	6

c. Vehicle Loading. The test vehicle shall be loaded in accordance with the mission profile. A sample load schedule is provided in Table 3.

TABLE 3. SAMPLE VEHICLE LOAD SCHEDULE

LOAD	TEST PHASES
None	1 and 2
100% of Rated Payload	3 through 6
None	7 through 10
75% of Rated Payload	11 through 14
None	15 through 18
100% of Rated Payload	19 through 22

d. Ambient Storage. During many portions of the test duration, the test item will not be participating in any test events. During these times, the vehicle will be stored at ambient conditions in a sheltered location. The facility should be kept relatively protected from the environment. The location could be used for preventive maintenance checks and services (PMCS) activities, inspections, photographs, and other miscellaneous activities. There is no specific requirement for the timing or duration of ambient storage events except that ambient storage time exceeding four days shall be modified to minimize corrosion, as discussed below.

e. Ambient Storage in Excess of Four Days. If holidays, unscheduled shutdowns, or other unforeseen events require that the vehicle be stored in excess of four days, the vehicle shall be washed to remove contaminants and stored in a low humidity, preferably cool environment.

The purpose is to minimize corrosion by reducing the effect of those components that contribute to corrosion (i.e., removing contaminants, minimizing moisture, and reducing temperature).

f. Vehicle Washing. Washing shall not take place prior to a humidity event. Washing shall consist of low-pressure, high volume water. If necessary, local areas of heavily caked mud may be removed at any time.

g. Maintenance and PMCS. Maintenance will be performed as needed throughout the test and may need to be performed at any time. PMCS are performed between cycles and test years according to the maintenance schedule for the test item; however, the PMCS schedule may need to be modified to accommodate the accelerated nature of the test. More details are presented in Appendix D.

4.7 Final Inspection.

At the completion of full service life corrosion tests, a system teardown inspection will be conducted. This will require disassembly of major test item subcomponents and lap seams, and cutting and opening of areas with crevice joints. This procedure is required to determine the effects of corrosion in areas that were not accessible during post test year inspections. This inspection is considered destructive in nature and will render the test item unfit for repair. It is a critical detailed assessment of all parts of the test item. All parts will be assigned an appropriate corrosion stage documented in the appropriate subassembly TIR and photographed. Disassembly should be accomplished in conjunction with appropriate Technical Manual (TM)/Interactive Electronic Technical Manual (IETM) procedures. All other test item discrepancies will be documented in individual TIRs.

5. DATA REQUIRED.

5.1 General.

Data specified in TOPs 02-2-505 and 02-2-506.

5.2 Test Item Characterization.

a. Data plate information (manufacturer, model, and serial number) and characteristic photographs.

b. Test item configurations and weight(s).

5.3 Initial Inspection.

a. Test item deficiencies, maintenance/repairs performed.

b. Film thickness and locations.

5.4 Fresh Water Splash Testing.

a. Description and photographs of splash patterns.

b. Road speeds of splash trough traversal.

5.5 Test Monitoring Coupons and Scribes.

a. Initial coupon masses.

b. Locations and orientations of coupon racks.

c. Photographs of coupon rack locations.

d. Locations and photographs of scribes (if applicable).

5.6 Test Events.

a. Conductivity or salinity of solutions for corrosion events.

b. Number and order of corrosion and durability events performed (one cycle) and the number of test years.

c. Number and dates when humidity events performed.

d. Fording depth and number of events performed.

e. Maintenance data in TIRs.

f. Description, stage and photographs of corrosion by component.

g. Final coupon masses.

h. Daily weather data: temperature, relative humidity, dew point temperature, and wind speed.

5.7 Final Inspection.

a. Test item deficiencies.

b. Description, stage, and photographs of corrosion by component.

c. Special tools required to remove components or parts.

d. Effectiveness of corrosion prevention and control procedures (if applicable).

6. PRESENTATION OF DATA.

6.1 General.

As specified in TOPs 02-2-505 and 02-2-506.

6.2 Test Item Characterization.

Presented in narrative, tabular, and pictorial form.

a. Table or photograph of data plate displaying vehicle identification data.

b. Narrative description of test item configurations and table of weights.

6.3 Initial Inspection.

a. Narrative and/or tabular display of test item deficiencies.

b. Table of film thickness measurements. An example is presented in Table 4.

TABLE 4. FILM THICKNESS MEASUREMENTS

LOCATION	THICKNESS (mils)
Middle of Hood	4.1
Driver's Side Door	4.4
Middle of Tailgate	3.9
Roof	3.8

6.4 Fresh Water Splash Testing.

Narrative description of splash pattern accompanied by pictures.

6.5 Test Monitoring Coupons and Scribes.

Data are presented in graphical and pictorial form.

a. Initial coupon masses are recorded in a spreadsheet for later use.

b. Narrative description of coupons and locations accompanied by photographs.

c. Narrative description and photographs of scribes (if applicable).

6.6 Test Events.

Data are presented in narrative, tabular, graphical, and pictorial form.

a. Graphical presentation of conductivity or salinity measurements throughout test. Example is presented in Figure 1.

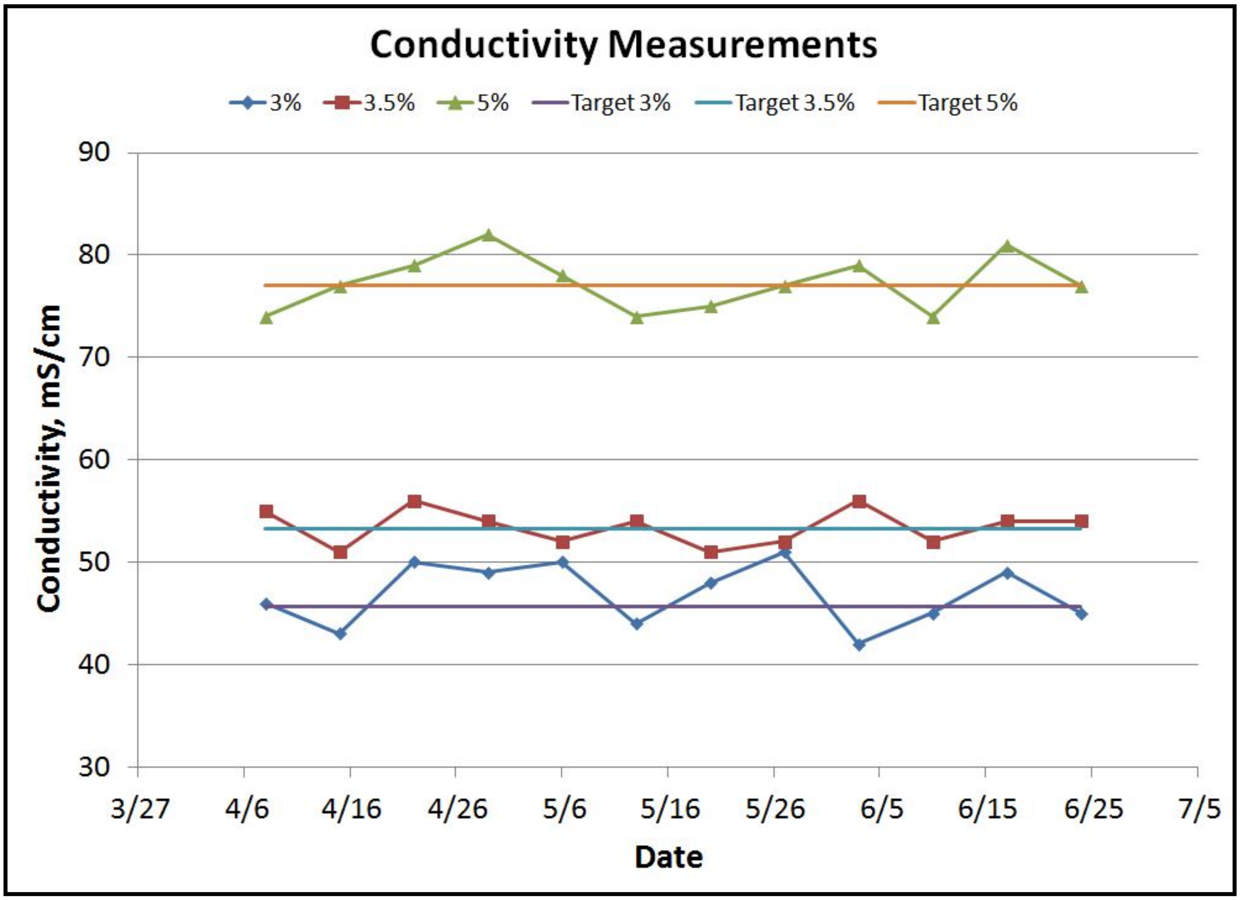

Figure 1. Example of Mist/Grit, Splash, and Fording Facilities conductivity measurements.

b. Tabular presentation of combined corrosion and durability cycle, including the number of test years.

c. Table of humidity events per test year. An example is presented in Table 5.

TABLE 5. NUMBER OF HUMIDITY EVENTS PER TEST YEAR

TEST YEAR	NUMBER OF HUMIDITY CHAMBER EVENTS
1	3
2	4
3	5
4	4

d. Table of fording events per test year.

e. Compilation of maintenance data presented in tables and graphs.

f. Photographs of corrosion by component with descriptive caption and corrosion stage identified.

g. Graphical presentation of corrosion rates presented by mass loss, penetration, or both. Examples are presented in Figures 2 and 3.

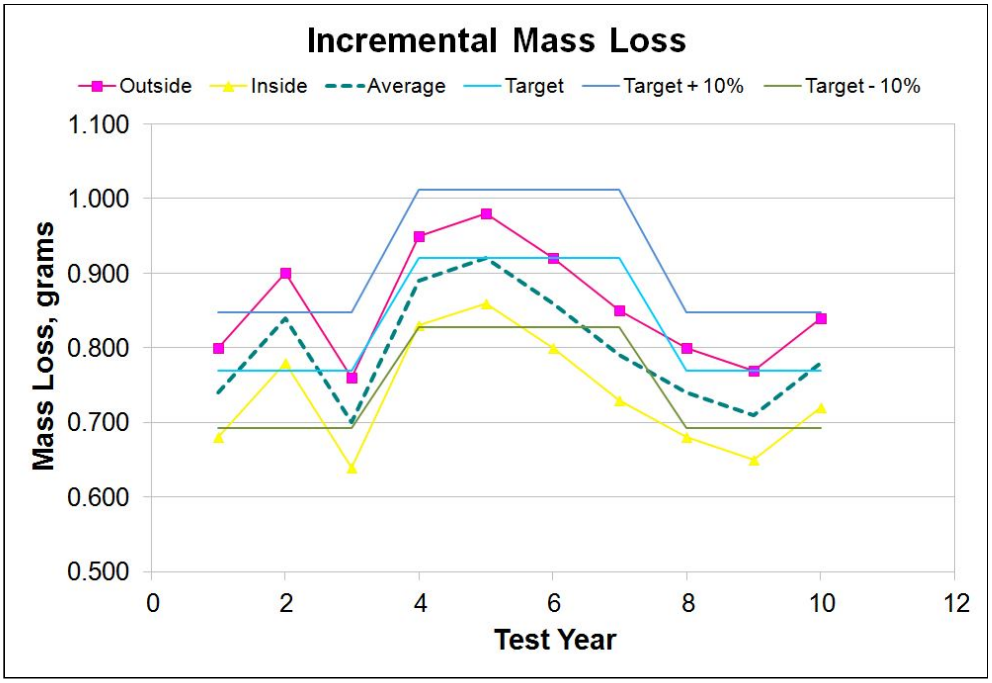

Figure 2. Example incremental Mass Loss coupon data.

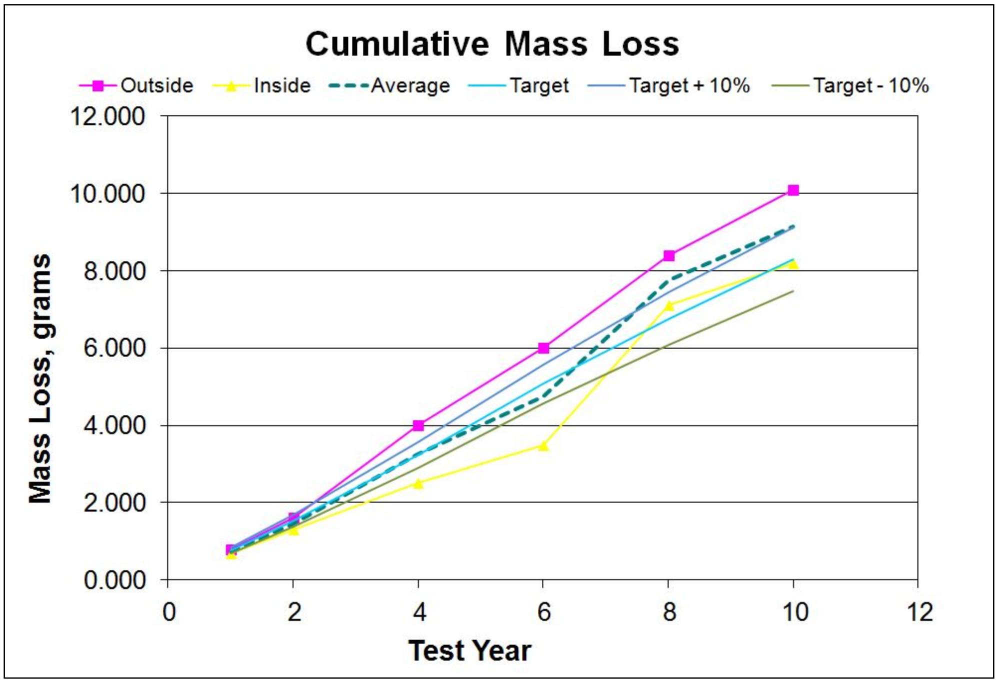

Figure 3. Example cumulative Mass Loss coupon data.

h. Graphical display of weather data (temperature, relative humidity, dew point temperature, and wind speed). Examples are presented in Figures 4 and 5.

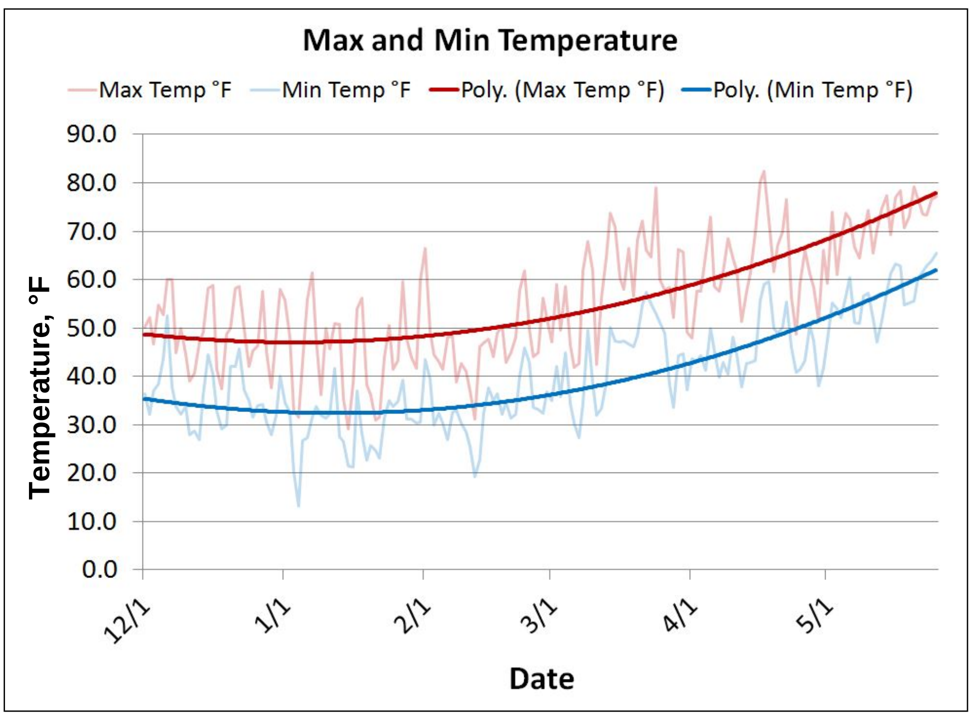

Figure 4. Example maximum and minimum temperature data.

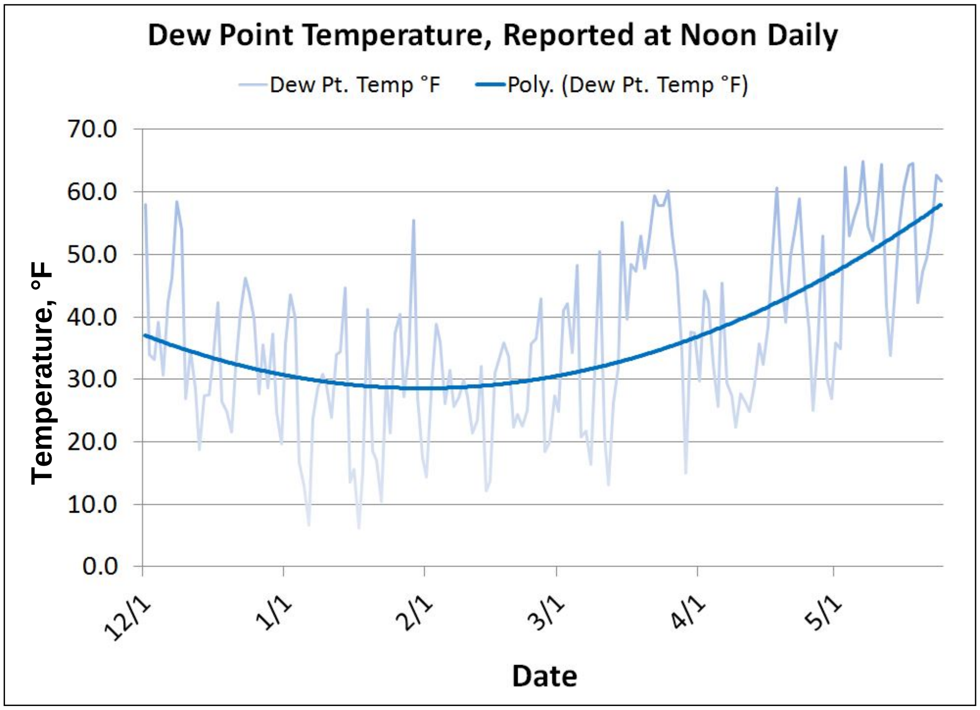

Figure 5. Example dew point temperature data.

6.7 Final Inspection.

a. Narrative and/or tabular display of test item deficiencies.

b. Photographs of corrosion by component with descriptive caption and corrosion stage identification.

c. Table of special tools required to remove components or parts.

d. Narrative description of effectiveness of corrosion prevention and control procedures with photographs (if applicable).

APPENDIX A. CORROSION FACILITY DESCRIPTION/PROCEDURES.

A.1. SALT SPLASH TROUGH/SALT MIST BOOTH.

A.1.1 Purpose.

The purpose of this facility is to apply a salt solution to all exposed external surfaces of the test item as would be experienced during normal driving conditions. As the name implies, it consists of two facilities: a shallow trough of salt water which splashes the vehicle/item's underside and a booth in which the salt water is misted over the item. The vehicle shall pass through each facility as part of this test cycle. The salt splash trough will expose the undercarriage of the vehicle to high concentration salt solutions that are present on roadways, typically from road deicing salts. The application includes exposure to fine mists from elevated speed travel. The salt mist booth applies a corrosive salt solution to all areas of the vehicle by creating a fine mist all around the vehicle.

A.1.2 Physical Layout – Salt Splash Trough.

The salt splash trough is covered and approximately 23 m (75 ft) long. The salt splash solution is 5% sodium chloride (NaCl) solution, by weight, mixed with water. The vehicle will pass through the trough at different entry speeds such as 56, 40, and 24 km/hr (35, 25, and 15 mph). The intent of the varying entry speeds is to ensure a variety of wetting scenarios that uniformly yet realistically wet the underside of the vehicle. As a result, the entry speeds may be modified to achieve uniform and realistic wetting of different vehicle systems. The solution level will be checked daily to ensure a consistent depth of nominally 5 cm (2 in.). The salt solution concentration will be checked weekly and when replenished.

A.1.3 Physical Layout – Salt Mist Booth.

a. The salt mist booth is an enclosed work bay. Spray nozzles are positioned across the sides and top of the facility to provide full salt spray application to all exterior surfaces on the top, sides, front, and back of the vehicle. Nozzle positioning may be optimized for each vehicle design that undergoes testing to ensure that all surfaces are properly wetted. The test item will be positioned in the center of the salt spray booth. The entrance and exit doors to the facility will be closed during spraying to ensure wind will not affect the spray pattern. The spray time will be approximately 3 minutes. The spray nozzles and all of the equipment associated with the holding tank, mixing tank, and spray application system will be inspected weekly.

b. The salt solution contains contaminants representative of elements found in the various natural environments that the vehicle is intended to operate. The solution must be carefully prepared to avoid formation of precipitates. The sodium bi-carbonate must be dissolved separately in water and then added to the solution of the other materials. If all solids are added together, a dry insoluble precipitate can form. The solution shall consist of the following mixture by weight:

(1) 2.7% Sodium Chloride (NaCl).

APPENDIX A. CORROSION FACILITY DESCRIPTION/PROCEDURES.

(2) 0.3% Calcium Chloride ($CaCl_2$).

(3) 0.225% Sodium Bi-Carbonate ($NaHCO_3$).

A.2. GRIT TROUGH.

A.2.1 Purpose.

The purpose of the grit trough is to introduce small particles into various crevices and joints on the underside of the vehicle. Grit will accumulate in the crevices. The accumulated grit, or poultice, will increase the time of wetness underneath its surface and sustain the contaminants against the surface of the vehicle. The grit also adds some abrasive stresses to the coatings and other material systems they contact.

A.2.2 Physical Layout.

The trough is covered and approximately 23 m (75 ft) long with a sloping entrance and exit. The grit depth should be maintained at approximately 15 cm (6 in.). Bumps (20 cm (8 in.) wide and 10 cm (4 in.) tall) can be added to the trough to induce body twisting and flexing. The grit used within the trough will contain Gleason ball clay (fire clay dust), ASHTO# 10 (crusher dust), and beach sand. The solids will be mixed in equal parts by volume. Water shall be added at a ratio of 6:1 by volume. Final consistency is liquid rather than mud-like. Salinity will be adjusted to 3% by the addition of a concentrated salt solution to match the salt mist booth (2.7% NaCl, 0.3% CaCl, 0.225% NaHCO3). The test vehicle shall pass through the trough at speeds of 24 km/hr (15 mph) or the maximum safe speed at these conditions. Observation of the consistency of the grit trough solution will be made weekly. The salinity of the grit trough will be monitored and adjusted weekly or as needed (due to rain events or replenishment).

A.3. FORDING BASIN.

A.3.1 Purpose.

The purpose of the fording basin is to simulate a beachfront landing. This basin will contain a 3.5% NaCl by weight salt-water solution to simulate salinity conditions found in seawater. This event will introduce corrosive waters (salt water) into most areas of the vehicle below the fording depth. Timing of this event is after washings to ensure that the fording pond does not remove contaminants from the vehicle. This may increase corrosion in areas (below the fording level) where contaminants do not easily collect (e.g., crevices).

APPENDIX A. CORROSION FACILITY DESCRIPTION/PROCEDURES.

A.3.2 Physical Layout.

The shallow water fording basin at Munson Test Area (MTA) measures 60 m (197 ft) in length and 6 m (20 ft) in width. The basin and all subsequent road courses are described in TOP 01-1-011A[3]. At both ends of this trough is a sloping entrance measuring 14.8 m (48.5 ft) in length. At the end of this ramp, the vehicle is immersed to a depth up to 152 cm (60 in.) for a total distance of 30.5 m (100.0 ft). Exit is through a ramp similar to that used for entrance. The fording basin can be shorter in length as long as the entire vehicle is able to be immersed to the proper depth based on the vehicle or equipment profile or capabilities.

A.4. SALINITY MONITORING.

The salinity of the solution is monitored by measuring its conductivity. This is compared to experimentally derived conductivity values of a laboratory prepared solution. Since this solution is a ratio of chemicals, the conductivity is unaffected by the volume from which the measurement is taken. The solutions should be within +/- 10% of the appropriate conductivity and subsequent salinity. Deviations from theses ranges should be adjusted by adding additional solute, in their proper ratios, to increase conductivity or by adding water to decrease conductivity.

A.5. PRIMARY ROADS.

A.5.1 Purpose.

The purpose of the primary road is to induce high frequency vibrational forces on joints in order to strain underbody components. These forces may cause some abrasive action. Higher speeds may also drive contaminants into crevice areas.

A.5.2 Physical Layout.

The course is an evenly paved surface capable of allowing continuous travel of the vehicle at 72 km/hr (45 mph). The oval-shaped facility consists of two straight sections, each 0.40 km (0.25 mi) long, joined at each end by 0.40-km (0.25-mi) sections of regular curvature to form an oval totaling 1.6 km (1.0 mi) in length. The driver will enter the course and accelerate the vehicle to a maximum speed of 72 km/hr (45 mph). The speed will be maintained for the designated number of laps, with slowing allowed only as required for safety purposes.

APPENDIX A. CORROSION FACILITY DESCRIPTION/PROCEDURES.

A.6. SECONDARY ROADS (GRAVEL ROAD).

A.6.1 Purpose.

The purpose of the secondary road is to impart coating damage caused by stone impingement on the underbody of the vehicle. The gravel road also provides a high frequency, low amplitude input on the underbody and other body components, which may act as abrasive forces. Secondary roads are also traversed in the process of accessing the Trails and Cross-Country Roads.

A.6.2 Physical Layout.

An improved gravel road course at MTA will be used to provide secondary road mileage. The course is a 3.2-km (2.0-mi) loop with left and right curves. The surface consists of compacted gravel that is maintained by grading. The course is traveled at varying speeds consistent with safe vehicle operation. Maximum traveling speed is expected to be 56 km/hr (35 mph).

A.7. CROSS-COUNTRY ROAD (ROLLING HILLS).

A.7.1 Purpose.

The purpose of this portion of the test is to subject the vehicle to twisting and turning motions associated with traveling on cross-country terrain. In order to access the cross-country road, the vehicle must traverse 2.7 km (1.7 mi) of the Secondary Roads discussed above.

A.7.2 Physical Layout.

Cross-country roads will be simulated using a rolling hill course at MTA. The course was designed to provide short, closely spaced grades. As a vehicle alternates between inclines and declines on this course, the engine and power train are subjected to rapid variations in loading. The surface consists of crushed stone that is compacted with stone dust binder. The course is 0.6 km (0.4 mi) in length and contains a paved turn-around section at both ends. This section will be traveled at 16 to 24 km/hr (10 to 15 mph). The course simulates cross-country conditions by using 30.5-cm (12.0-in.) offset space bumps throughout the course.

A.8. TRAILS (BELGIAN BLOCK).

A.8.1 Purpose.

The purpose of this portion of the test is to subject the vehicle to intermediate frequency and force inputs typical of trails. In order to access the trails, the vehicle must traverse 1.6 km (1.0 mi) of the Secondary Roads discussed above.

APPENDIX A. CORROSION FACILITY DESCRIPTION/PROCEDURES.

A.8.2 Physical Layout.

The facility consists of 1.1 km (0.7 mi) of a Belgian Block course at MTA. The facility is paved with unevenly laid granite blocks forming an undulating surface. It duplicates the rough cobblestone road found in many parts of the world. The course is useful as a standard rough road for accelerated tests of wheeled vehicles and is generally included in cycles of courses for vibration studies. The motion imparted to a vehicle is a random combination of roll and pitch and high frequency vibrations imparted by the granite paving blocks. The section will be traveled at 32 to 40 km/hr (20 to 25 mph).

A.9. FRAME TWISTER.

A.9.1 Purpose.

The purpose of the frame twister is to provide a dynamic flexural input to the vehicle at the beginning and end of the test. The frame twister will be executed after phase 2 and the last test year. The purpose of executing the frame twister after cycle 2 is to flex the joints and allow initiation of corrosion in broken joints and seams early in the test. The purpose of the frame twister at the end of the last test year is to fully stress all structural components to ensure integrity after the cumulative corrosion.

A.9.2 Physical Layout.

The frame twister was designed to deflect the opposite wheels of the vehicle in alternately contrary directions. This is accomplished by dividing the road in half and creating two separate series of hills (waves) on either side. These waves are 4.3 m (14.0 ft) from peak to valley and are 180 degrees out of phase (i.e., when one wheel is at a peak the wheel on the opposite side of the vehicle is in a valley). At each peak's maximum point the wheel is raised 0.6 m (2.0 ft) above the average height. At each valley's minimum point the wheel is lowered 0.6 m (2.0 ft) below the average height. The total length of the course is 135 m (443 ft). The frame twister shall be traversed once at a speed not to exceed 8 km/hr (5 mph).

A.10.HUMIDITY CHAMBER.

A.10.1 Purpose.

The purpose of the humidity chamber is to create high temperature and humidity conditions that will accelerate the natural corrosion process. The effects of the chamber conditions will accelerate the reaction of the contaminants applied by the different test events with any exposed material on the vehicle.

APPENDIX A. CORROSION FACILITY DESCRIPTION/PROCEDURES.

A.10.2 Physical Layout.

The humidity chamber requires a working area sufficient to condition the equipment being tested. Appropriate equipment is required to measure and control the temperature and humidity at the specified levels. Circulation fans shall be employed to provide a moderate flow of the high humidity air throughout the chamber. The temperature will be held at 48.9 °C +/- 2.8 °C (120 °F +/- 5 °F). The relative humidity will be maintained at 100 percent in a condensing state. The resulting water fog will provide a condensation rate of 3 milliliters per hour (ml/hr) (0.1 ounces per hour (oz/hr)) in collection devices having a horizontal collection area of 80 cm^2 (12.4 $in.^2$). During designated test cycles, the vehicle will be positioned in the humidity chamber for an eight-hour period beginning when the temperature and humidity parameters are achieved. The temperature and humidity will be maintained at the specified levels for the duration of exposure.

APPENDIX B. BACKGROUND INFORMATION AND TEST METHODOLOGY.

PROJECTED FIELDING PROFILE/SEVERITY OF EXPOSURE.

The projected fielding profile and subsequent exposure severity for the accelerated corrosion test for military vehicles and equipment is referenced from a study titled Development of a US Marine Corps Corrosion/Durability Road Test Methodology[4]. This study goes into detail about fielding profiles and real world data used to derive the target corrosion rates. These suggested incremental and cumulative target corrosion rates are presented in Tables B-1 and B-2, respectively. Target corrosion rates can be tailored depending on the intended fielding profile of the vehicle or equipment.

TABLE B-1. INCREMENTAL TARGET CORROSION RATES

TEST YEARS	**TARGET CORROSION RATE**	
	MASS LOSS PER TEST YEAR (g)	**PENETRATION PER TEST YEAR (µm)**
First 1/3	0.77	32.0
Middle 1/3	0.91	38.1
Last 1/3	0.77	32.0

NOTE: Target corrosion rate in grams is based on coupons measuring 2.54 cm x 5.1 cm x 0.32 cm (1 in. x 2 in. x 0.125 in.).

APPENDIX B. BACKGROUND INFORMATION AND TEST METHODOLOGY.

TABLE B-2. CUMULATIVE AVERAGE TARGET CORROSION RATES

TEST YEARS	AVERAGE TARGET CORROSION RATE	
	MASS LOSS (g)	PENETRATION (µm)
1	0.77	32.0
2	1.54	64.0
3	2.30	96.0
4	3.07	128.0
5	3.84	160.0
6	4.61	192.0
7	5.38	224.0
8	6.29	262.1
9	7.21	300.2
10	8.12	338.3
11	9.03	376.4
12	9.95	414.5
13	10.86	452.6
14	11.78	490.7
15	12.55	522.7
16	13.31	554.7
17	14.08	586.7
18	14.85	618.7
19	15.62	650.7
20	16.39	682.8
21	17.15	714.8
22	17.92	746.8

NOTE: Target corrosion rate in grams is based on coupons measuring 2.54 cm x 5.1 cm x 0.32 cm (1 in. x 2 in. x 0.125 in.).

APPENDIX C. EVALUATION TECHNIQUES.

During corrosion testing, the test item will be evaluated for signs of corrosion. Several techniques, some unique to the items being evaluated, will be used for evaluation. These are discussed below.

C.1. STAGES OF CORROSION.

a. The stage of corrosion in a given area is evaluated based on a numeric rating scale. The rating scale is based on the severity of corrosion. The rating scale and photographic examples of the corrosion stages are provided below in Table C-1 and Figure C-1, respectively.

TABLE C-1. CORROSION RATING SCALE

NUMERIC RATING	DESCRIPTION
0	No visible signs of corrosion
1	Surface corrosion is visible but little to no loose corrosion product is present/Paint shows early signs of blistering
2	Surface corrosion is visible with loose corrosion product on surface/Paint is more severely blistered
3	Significant corrosion has occurred resulting in a reduction in thickness or cross-section/Paint is blistered and broken with significant corrosion underneath
4	Severe corrosion has occurred resulting is significant metal loss or perforation of component

APPENDIX C. EVALUATION TECHNIQUES.

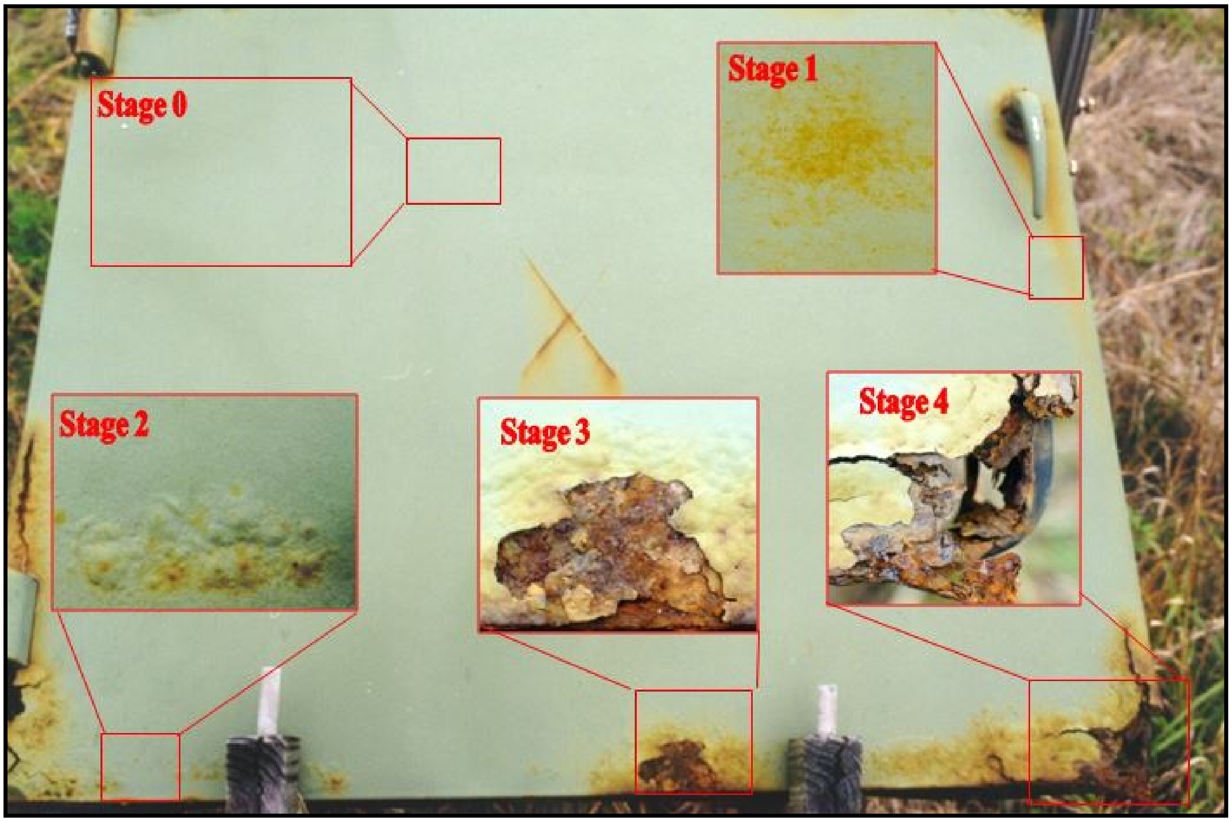

Figure C-1. Examples of corrosion stages.

C.2. CORROSION RATE.

The corrosion rate is determined by the mass loss of coupons. The coupons are 1008 steel and measure 2.54 cm x 5.08 cm x 0.3175 cm (1 in. x 2 in. x 0.125 in.) with a centered 0.67-cm (0.265-in.) hole used for mounting. They are handled with latex gloves to prevent contamination from skin oil which could help to prevent corrosion. The coupons are cleaned with acetone and weighed prior to exposure. The coupons are mounted on an aluminum rack with plastic hardware to isolate the coupons from contact with other metals. The aluminum racks are mounted to the test item using existing hardware with plastic spacers to isolate dissimilar metals when possible. These coupons are exposed on the test vehicle for a specific number of test years. Following exposure, the coupons are removed, glass bead blasted to remove all corrosion, cleaned with acetone, and weighed. Initial and final mass measurements (before exposure and after corrosion removal) determine mass loss due to corrosion. This mass loss value can be converted into penetration (µm) through calculation.

APPENDIX C. EVALUATION TECHNIQUES.

$$penetration = \frac{mass\ loss}{density \times surface\ area} = \frac{mass\ loss}{\left(7.86\,g/cm^3 \times 30.6cm^2\right) \div 10{,}000\ \mu m/cm} = \frac{mass\ loss}{2.4 \times 10^{-2}\ g/\mu m}$$

C.3. FILM THICKNESS.

Film thickness measurements can ensure that protective coatings are being applied in appropriate amounts. Measurements should be taken in several areas on each surface to verify the coating thickness over the entire surface area of the test item.

C.4. SCRIBE CUTBACK/CREEPAGE.

a. A scribe is an intentional defect made through a coating system to the substrate. Defects are typically linear in nature and are made by repeatedly passing a scribe tool over a coating, using a straight edge as a guide, until the substrate is reached. This test is accomplished to determine the system's ability to inhibit underfilm corrosion.

b. Underfilm corrosion is identified as bubbling of the paint directly adjacent to this defect. The maximum distance this occurs at either side of the scribe is measured. The total cutback is the sum of these values. Sample scribes and measurements are presented in Figure C-2.

APPENDIX C. EVALUATION TECHNIQUES.

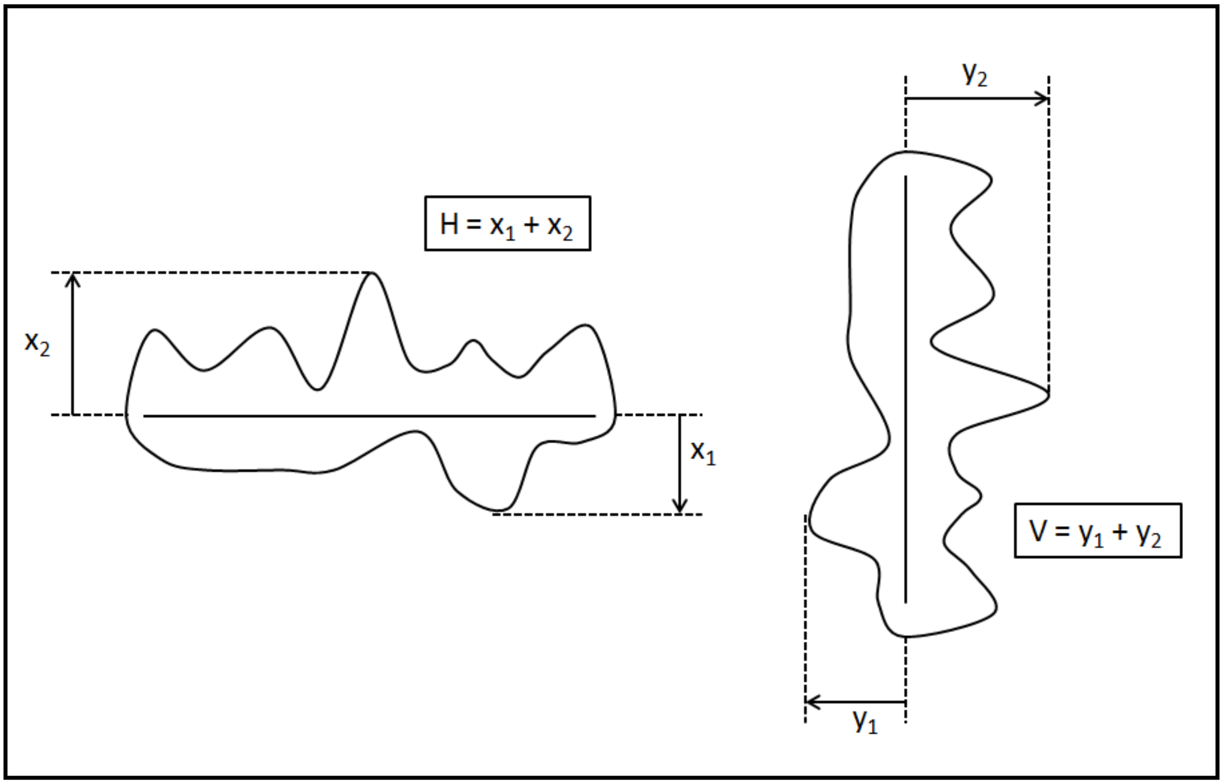

Figure C-2. Scribe cutback measurement technique.

APPENDIX D. EQUIPMENT MAINTENANCE.

Maintenance performed during the test should mirror the type of maintenance that is expected during actual field use of the equipment. The degree of acceleration that the corrosion test has on components and materials needs to be factored into the maintenance schedule. For example, components and materials whose aging does not accelerate with the corrosive input, such as grease and oil, should not be accelerated (i.e., not conducted in accordance with the regular maintenance schedule based on the acceleration rate of the test - one test “year” would not necessarily equal a “year” for required maintenance). The maintenance of these materials and other general maintenance will be performed at specified intervals designated by total driving mileage. However, other maintenance issues that are affected by the corrosive impact, such as cleaning, should be somewhat accelerated. Maintenance charts can be developed from the Preventive Maintenance Checks and Services (PMCS) sections of the TMs. Alternate schedules can be considered to accommodate the test schedule. For the purpose of this test, these PMCS intervals may be changed or altered by the test community to accommodate test scheduling and corrosion evaluation. Spot painting repair of areas affected by chipping during the endurance portion of the corrosion cycle will not be allowed; to do so would not allow for adequate evaluation of the test item topcoat, primer, pretreatment, substrate and base metal substrate system.

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APPENDIX E. ABBREVIATIONS.

ACDT	Accelerated Corrosion Durability Test
C	Celsius
$CaCl_2$	calcium chloride
cm	centimeter
ft	feet
g	gram
IETM	Interactive Electronic Technical Manual
in.	inch
IPT	Integrated Product Team
km	kilometer
km/hr	kilometers per hour
µm	micrometer
m	meter
mg	milligram
mi	mile
MIC	Microbial Induced Corrosion
ml/hr	milliliters per hour
mph	miles per hour
mS/cm	milliSiemens per centimeter
MTA	Munson Test Area
NaCl	sodium chloride
$NaHCO_3$	sodium bi-carbonate
oz/hr	ounces per hour
PMCS	Preventive Maintenance Checks and Services
TIR	Test Incident Report
TM	Technical Manual
TOP	Test Operations Procedure

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APPENDIX F. REFERENCES.

1. TOP 02-2-505, Inspection and Preliminary Operation of Vehicles, 4 February 1987.

2. TOP 02-2-506, Endurance Testing of Tracked and Wheeled Vehicles, 26 June 1981.

3. TOP 01-1-011A, Vehicle Test Facilities at Aberdeen Test Center and Yuma Test Center, 27 February 2012.

4. A. Sheetz, A. Field, S. Sampson, J. Repp, P.E., B. Mullis, M. Sime, Development of a US Marine Corps Corrosion/Durability Road Test Methodology, 2007.

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APPENDIX G. APPROVAL AUTHORITY.

CSTE-TM 15 October 2013

MEMORANDUM FOR

Commanders, All Test Centers
Technical Directors, All Test Centers
Directors, U.S. Army Evaluation Center
Commander, U.S. Army Operational Test Command

SUBJECT: Test Operations Procedure (TOP) 01-1-065 Accelerated Corrosion Durability, Approved for Publication

1. TOP 01-1-065, Accelerated Corrosion Durability, has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency. The scope of the document is as follows:

This TOP prescribes procedures for evaluating the durability of mobile equipment while being subjected to accelerated corrosion. Major factors to be considered when evaluating the effects of corrosion on mobile equipment include the intended operational environment, preventive maintenance checks and services, and corrosion monitoring methodology. Events used to accelerate corrosion and its effects include salt mist, salt splash, grit splash, high heat/high humidity, and shock and vibration input from various terrain.

2. This document is approved for publication and has been posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at https://vdls.atc.army.mil/.

3. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-TM), 2202 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

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MICHAEL J. ZWIEBEL
Director, Test Management Directorate (G9)

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Range Infrastructure Division (CSTE-TM), US Army Test and Evaluation Command, 2202 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: Automotive Directorate (TEDT-AT-AD), US Army Aberdeen Test Center, 400 Colleran Road, Aberdeen proving Ground, MD 21005-5059. Additional copies can be requested through the following website: http://itops.dtc.army.mil/RequestForDocuments.aspx, or through 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.