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Project - LTPC Phase II: Modification of Hentzen (Crosslink) Powder Coatings 6191-61003 for Enhanced protection to UV and MIC

Report on Technical Order 35-1-3 Review and Recommendations

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List of Acronyms

AFLCMC	Air Force Life Cycle Management Center
AFCPCO	Air Force Corrosion Prevention Control Office
AGE	Aircraft Ground Equipment
BOD	Biochemical Oxygen Demand
CAC	Corrosion Assessment Checklist
CCC	Corrosion Category Code
CONUS	Continental United States
COTS	Commercial-Off-the-Shelf
CPAC	Corrosion Protection and Control
CPC	Corrosion Preventative Compound
CST	Corrosion Service Team
DoD	Department of Defense
HAP	Hazardous Air Pollutants
LTPC	Low Temperature Powder Coating
MCRS	Mobile Corrosion Repair Services
MIC	Microbial Influenced Corrosion
PACAF	Pacific Air Forces
PMO	Program Management Office
SE	Support Equipment
SOW	Statement of Work
Sq.ft.	Square Feet
SWA	Southwest Asia
TM	Technical Manual
TO	Technical Order
USAF	United States Air Force
UV	Ultra Violet
VOC	Volatile Organic Compound

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Executive Summary

This report presents the review of Air Force Technical Order 35-1-3 and recommendations on military processes and corrosion maintenance employed as related to weatherability and microbially influenced corrosion (MIC) control at the PACAF locations. Battelle reviewed the Technical Manual – Corrosion Prevention and Control, Cleaning, Painting, and Marking of USAF Support Equipment (SE) also referred to as Technical Order (TO) 35-1-3 Change 5 released on 8 July 2015 for this report.

The TO 35-1-3 is a comprehensive document and it provides guidance for corrosion prevention, control, and mitigation activities to be undertaken during operations, maintenance, repair, and overhaul of Aircraft Ground Equipment (AGE) across the Air Force at organizational/unit, field, and depot levels. This report specifically focuses on evaluating the effectiveness or perceived effectiveness of the following topics covered in the TO as applicable to the PACAF locations;

1) Equipment storage and preventative cleaning cycles and requirement measures
2) Corrosion prevention regulation and guidance as a function of equipment and material
3) Corrosion guidance within prescribed tolerable limits, whereby the guidance allows for cleaning, corrosion repair methods, and subcomponent replacement or unit condemnation guidance.

Battelle visited PACAF locations at Kadena Air Base, Gunsan Air Base, and Andersen Air Force Base to evaluate the state of AGE at these locations from constant exposure to ultra violet (UV) and potentially from microbially influenced corrosion (MIC). During the visits, Battelle toured the corrosion repair facilities and had conversations with the AGE and Corrosion Control Point of Contacts (POCs) at these locations to understand the processes and procedures followed to prevent and mitigate corrosion of AGE/SE. The PCAF locations we visited followed the TO guidance for annual corrosion assessments and subsequent repairs of the SE based on those assessments. Their corrosion repair facilities were well equipped with equipment and personnel to support the prescribed corrosion repair methods in the TO. We were unable to observe or validate the quality assurance processes in place relative to the materials to be used during the wash cycles with the POCs but all of them confirmed that indoor space is at premium resulting in the AGE stored on open lots throughout the year except during inclement weather such as typhoons when it was brought indoors.

Over the past few years, Battelle has provided technical and programmatic support to the United States Marine Corps (USMC) Corrosion Prevention and Control (CPAC) program. The CPAC program is responsible for maintaining combat readiness of over 100,000 ground assets of which, large numbers are in environments like those at PACAF locations. Since the substrates and coatings stackup on the Marine Corps assets are like the AGE, established practices and processes used by the Marines are referenced in several sections of this report where we believe emulating these practices could benefit the Air Force's ability to combat corrosion issues on AGE.

Finally, this report identifies miscellaneous shortfalls within the TO and presents topics to be incorporated into the next revision of the TO. In its last section, the report proposes collaborative and theoretical options for consideration by the Support Equipment and Vehicles Division to combat and mitigate corrosion on the AGE at PACAF locations.

1.0 Introduction

1.1 Background

The Support Equipment and Vehicles Division of the Air Force Life Cycle Management Center (AFLCMC) funded a project to Battelle to modify Hentzen (Crosslink) Powder Coatings No. 6191-61003 for enhanced performance against ultraviolet (UV) exposure and microbiologically influenced corrosion (MIC) to support Aerospace Ground Equipment (AGE) at Pacific Air Force (PACAF) locations. The objective is to demonstrate this modified non-chromate, low Volatile Organic Compound (VOC) and Hazardous Air Pollutant (HAP)-free, powder coating on coupons machined from aluminum and steel alloys commonly used on AGE and in aviation. If successful, the COTS LTPC would offer the Department of Defense (DoD) a VOC and HAP free material coating system capable of supporting PACAF AGE.

The Technical Order 35-1-3 provides guidance for corrosion prevention, control, and mitigation activities to be undertaken during operations, maintenance, repair, and overhaul of AGE across the Air Force at organizational/unit, field, and depot levels.

1.2 Scope

The scope of this report is for Battelle to review Technical Order 35-1-3, and document military processes and corrosion maintenance employed as related to weatherability and MIC control at the PACAF located air bases. Battelle reviewed the methods in T.O. 35-1-3 and evaluated their effectiveness or perceived effectiveness with regards to the following:

1) Equipment storage and preventative cleaning cycles and requirement measures
2) Corrosion prevention regulation and guidance as a function of equipment and material
3) Corrosion guidance within prescribed tolerable limits, whereby the guidance allows for the following;
    a) Cleaning and returning to service
    b) Corrosion repair methods, once damage is determined to be outside of prescribed tolerable limits
    c) Subcomponent replacement or unit condemnation guidance, once repair of corrosion damage is deemed too expensive
4) Miscellaneous shortfalls and improvements for T.O. 35-1-3

Following the review of the T.O., Battelle provided recommendations to improve local work practices and processes to combat weathering and MIC damage to PACAF AGE units. Alternative or corrosion preventative methods for USAF consideration and inclusion into T.O. 35-1-3, specific to LTPC application are also included.

1.3 Approach

In this report we have summarized our observations of corrosion prevention and control activities during visits to the PACAF locations at Kadena Air Base, Gunsan Air Base, and Andersen Air Force Base. The recorded observations are then reviewed for compliance with the guidance provided in T.O. 35-1-3. Battelle also visited the AGE maintenance depot at Hill AFB to observe the corrosion prevention and control processes performed during the maintenance, repair, and overhaul operations on bomb lifts, munition trailers, and generators. Finally, alternatives and new techniques to improve practices and processes used to combat corrosion and MIC damage to PACAF AGE units are proposed based on Battelle's experience in working with other DoD agencies. The observations and high-level recommendations to be incorporated in this report were discussed in a meeting with the Air Force Program Manager and the Air Force Corrosion Prevention Control Office (AFCPCO) at Robins Air Force Base to gain their insight and thoughts.

Over the past few years, Battelle has provided technical and programmatic support to the Marine Corps Corrosion Prevention and Control (CPAC) program, responsible for maintaining combat readiness of over

100,000 ground assets of which, large number are in environments like those at PACAF locations. Since the substrates and coatings stackup on the Marine Corps assets are like the AGE, established practices and processes used by the Marines are referenced in several sections of this report where we believe emulating these practices could benefit the Air Force's ability to combat corrosion issues on AGE.

2.0 Technical Order 35-1-3 Review

2.1 Overview of the Technical Order

Battelle reviewed the TO 35-1-3 Change 5 released on 8 July 2015 for corrosion prevention and control at various levels with specific attention to the guidance provided for activities to be performed at the organizational and intermediate levels. Further, the review focused on activities included in the scope of work.

2.2 Equipment Storage

Chapter 7 of the TO 35-1-3 provides guidance specific to SE located in the Southwest Asia (SWA) region. Section 7.2.4 provides following guidance for equipment storage in these regions: "In the harsh environments of SWA it is recommended that SE be stored indoors or under covers. Permeable fabric covers are recommended for short and long-term storage of equipment. These covers can be purchased or locally manufactured. They allow for airflow to prevent condensation and sand/dust buildup on/in the equipment".

The TO does not provide similar specific guidance for storage of AGE located in other regions. The guidance provided in section 7.2.4 could be implemented across PACAF locations.

2.2.1 Protection from UV and Weather

The T.O. does not specifically address this aspect of protection of the AGE. From discussions with unit representatives at the three PACAF locations, we learned that the AGE is always stored outdoors and without covers except when it is brought indoors into maintenance hangar for repair or to keep it secured under extreme weather or typhoon conditions.

AGE stored at Andersen AFB

AGE stored at Kadena AB

Figure 1 Observed storage of SE at PACAF locations

The storage of support equipment (SE) or AGE in this manner allowed for intense UV exposure as well as no protection from other environmental conditions such as water, snow, ice, heat, dirt, smog, humidity, grime and salts. While UV exposure could slow the advancement of MIC as it is known to be an excellent disinfectant in industrial processes, it is also known to cause significant damage to coatings. Exposure to

UV radiation over time can have detrimental effects on the polyurethane coating applied to SE to protect it from corrosion. Once the coatings start to degrade, microorganisms can invade the SE and obtain protection from direct UV; MIC then also becomes an issue.

The Marine Corps CPAC program has had marked success in the storage of their ground assets in several types of structures to limit the UV and weathering exposure. Many times, these structures will include dehumidification units to maintain controlled humidity for corrosion prevention. These structures could be brick and mortar maintenance bays, interim relocatable tension fabric shelters, or T- shelters with awnings.

Permanent Structure

Tension Fabric Shelter

Open Shelters

Figure 2 Examples of various storage structures used by Marine Corps for ground assets

2.3 Regulations and Guidance for Corrosion Prevention

2.3.1 Corrosion Scoring

Corrosion scoring of SE is discussed in section 3.3.1. Table 3-2 of the T.O. offers descriptions of the deterioration of the SE due to corrosion. These are a fair guidance for the technician who is scoring the asset. The concern here is the accuracy of the assessment by the new airman. Is there enough information for him of her to make an accurate assessment of the unit?

The Marine Corps CPAC program has implemented a Corrosion Assessment Checklist which is utilized by the Corrosion Service Teams to assess each ground asset. The checklist asks the assessor yes and no questions about the asset being assessed. The checklist takes the person providing the assessment through the various components and areas of the asset and asks pointed questions as to the level of deterioration seen in each area. Once the checklist is completed by the assessor it is evident as to the corrosion category code (corrosion score) the asset should be given. A comprehensive training for corrosion assessment is provided and is required for conducting corrosion assessments.

The T.O. clearly discusses in section 3.3.1.1.1 the areas the assessor should be looking at as well as what deterioration they should be looking for. The basics of a checklist are already there. It is our recommendation to put those guiding principles into a format that may lead the airman to give a more accurate corrosion score and allow airmen across the Air Force to more consistently assess SE assets. If the Air Force is interested in the Marines corrosion assessment checklist, Battelle would ask the CPAC PMO if we could share the checklist with the Air Force.

2.3.2 Coating Stack-up Guidance

Table 3-1 section 3.3.1.2.1 provides guidance on coatings stack-up and applications to be performed during maintenance, repair, and overhaul of SE at various levels organization/unit, interim, and depot levels. The guidance is comprehensive and the corrosion repair facilities at the PACAF locations on the visit (Kadena, Gunsan, and Andersen) follow the intermediate level guidance to prevent and mitigate corrosion on the AGE.

2.3.3 Undercoat

Section 3.22 of TO 35-1-3 refers to undercoating of SE but very little detail is discussed, or definitive guidance provided in regard to undercoating of SE. However, much of the observed corrosion was seen on the undercarriage of the support equipment. Debris such as rocks tend to chip the coating under the equipment making it more susceptible to corrosion. Hard flexible coating protecting these areas could be very beneficial in increasing the life span due to corrosion of SE. The corrosion repair facilities at Kadena and Gunsan do not apply undercoating to the SE whereas, the contractor (Milspray Technologies LLC) operated corrosion repair facility at Andersen AFB has recently acquired approval to apply Tectyl 2423, a low Volatile Organic Content (VOC), air dry, high solids, emulsion coating as an undercoating to the SE and has started undercoat application.

Figure 3 Undercarriage corrosion observed at Kadena AB

The Marine Corps CPAC program has had great success with the underbody coating Tectyl 2423, a low VOC, air dry, high solids, emulsion coating. It works well with both ferrous and non-ferrous metals with a single application. The cured film is hard and flexible. Milspray Technologies LLC is a primary provider of mobile corrosion repair services (MCRS) to the CPAC program which includes application of bed liner and undercarriage coatings.

2.4 Corrosion Guidance on Cleaning

2.4.1 Wash Interval

Corrosion is the process by which metal degrades in the presence of various oxidizing agents in the environment. Perhaps the most common, affordable method of protecting metal from corrosion is simply to cover it up with a layer of paint. The process of corrosion involves moisture and an oxidizing agent interacting with the surface of the metal. Thus, when the metal is coated with a protective barrier of paint, neither moisture nor oxidizing agents can come in contact with the metal itself and no corrosion occurs. However, paint itself is vulnerable to degradation. When paint degrades or is damaged to the point that the underlying metal becomes exposed, the electrochemical process can begin. Environmental contaminants such as salts can increase the rate at which this process deteriorates the underlying materials. Frequent washing away of these environmental oxidizing agents is a good way to slow the process of corrosion. The more frequent the better, especially in salty environments such as the case with the bases at PACAF locations. It should be noted that ensuring that once washed, attempts to thoroughly

dry the assets should be made as water/moisture is a key contributor to corrosion. Every attempt should be made to remove excess water from crevices where it may remain.

Based on the severity of corrosion in the PACAF zones, Table 2-1 in TO 35-1-3 states the recommended wash cycle for support equipment is 90 days. Based on testing performed at Battelle with regards to the MIC samples collected at the PACAF locations we have seen the growth of these bacteria and fungus on painted metal panels in a matter of days in optimum conditions.

Based on these observations it may be advantageous to decrease the cycle time between washings to 30 or 60 days.

2.4.2 Wash Process

During the visit to the three PACAF locations and discussions, it was not clear if all AGE assets are washed in accordance with the 90-day wash interval requirement. The support function of the warfighter takes priority and under such circumstances, the wash intervals for the AGE exceeds the guidance.

2.4.2.1 Cleaning Materials

While cleaning compounds such as the ones listed in Section 2.1.6 of the TO are suggested for use when cleaning SE, these compounds should not be used outside of the recommended concentrations or dilutions. Cleaning compounds may impart Biochemical Oxygen Demand (BOD) to the wash water and increase the pH, thus providing a habitable environment for MIC-causing microorganisms. Therefore, use of excessive amounts of cleaning compounds should be avoided. Additionally, after washing with the cleaning compounds, a thorough rinse with just water should be performed in order to remove all potential carbon/food sources for the MIC-causing microorganisms.

2.4.2.2 Water Temperature

Use of hot water is optimal for reduction of potential MIC-causing microbes. Actively growing microbes should be killed by a high temperature wash, while sporulated organisms, though not necessarily killed, should be washed away by the water.

2.4.2.3 Water Assessment

Section 2.1.7.5.1 discusses assessing site wash water and the key parameters that should be monitored. There is no mention of how often the water should be assessed or who is responsible for assessing the water quality. It would be our recommendation that these two questions be addressed in the T.O. as well as the results of the assessment being documented for audit and historic tracking purposes.

2.4.2.4 Water Quality/Recycled Water

Section 2.1.7.6 is quite detailed on the requirements and testing cycle for closed loop water recycling systems. It is unclear however as to who has the responsibility of assessing this water.

Battelle was unable to get a good understanding of the wash intervals or the process, and water quality control followed at the three PACAF locations.

2.5 Clean and Return to Service

The Marine Corps CPAC has in place corrosion service teams (CSTs). The mission of the CSTs is "To provide Marine Force Commanders with the capability to combat the effects of corrosion on Marine Corps Ground Combat Equipment within the organization and to extend the time between required repairs at Corrosion Repair Facilities".

The CPAC CSTs are the means for implementing the set of corrosion control procedures for organizational corrosion activities and preservation defined in TM 4795-OR/1A. The CST services are

being implemented via mobile equipment and personnel. These teams go to specific units and work around the unit's normal work schedule to service the equipment. CST efforts involve assessing, categorizing, surface preparation, coating and application of corrosion inhibitors on thousands of pieces of ground combat and ground combat support equipment. The program's base-line has been established using the Corrosion Assessment Checklist (CPAC-CAC) developed by the CPAC Program Office. Once the CST completes the checklist they assign the asset a corrosion category code (CCC) similar to the corrosion scoring done by the Air Force. This CAC was presented to the Defense Science Board's Task Force on Corrosion, which indicated that replicating this approach across DoD would provide a solid basis for improvement. Capitalizing on assessments conducted since June 2004, the CPAC Program Office is using the collected data to make fact-based repair and prevention decisions, which would have been

Figure 4 CPAC Corrosion Service Team in Action

impossible without a corrosion assessment. Data obtained from the corrosion assessments is being used by unit commanders to identify candidates for CST efforts such as surface preparation, spot painting, and the application of Corrosion Prevention Compounds (CPCs). The data also is used in prioritizing assets to be cycled through CRFs and assist the Marine Corps in budgeting for corrosion prevention and corrective maintenance dollars, assessing equipment readiness, and identifying corrosion trends and problem areas. The CPAC program can monitor the effects of corrosion on equipment throughout its life cycle and impact future decisions.

2.6 Corrosion Repair Guidance Outside of Tolerable Limits

Section 3.3 of the T.O. discusses the requirements for painting at the field level. Section 3.3.1.2.1 states that the complete repaint criteria is: "a coating system is considered failed when over 75% of the total exterior surface displays obvious oxidation, bleaching, peeling, cracking, flaking, etc.".

The Marines Corps CPAC program has set in place guidelines for organizational repairs (CST). These guidelines state that no repairs over 1sq.ft. are to be completed at the organizational level, and any combination of repairs under 1 sq.ft. should not exceed a time limit of three hours. Any repairs exceeding these guidelines would be treated with CPC's and sent to the corrosion repair facility for resolution.

2.6.1 Component Replacement and Unit Condemnation of AGE

T.O. 35-1-3 does not discuss AGE unit condemnation once the cost of repairs would exceed what is considered too expensive. It is difficult for Battelle to recommend when an AGE unit should be condemned. As some units may be invaluable to the mission of the Air Force and need to be repaired regardless of cost.

The Marine Corps does use a category 5 in their corrosion scoring, that is a level that would condemn an asset. This corrosion category is not based on cost necessarily as much as it is based on the level of deterioration. The CPAC CAC states that an asset should be given a category 5 score if the frame is unsound. Meaning the frame is corroded or has physical damage to the point that the mechanical strength is lost. An asset can also be given a category 5 score if the overall condition of the asset has severe mechanical damage or deterioration to a degree that presents a safety hazard.

2.7 Miscellaneous Shortfalls and Improvements

2.7.1 Responsibility

The T.O. is quite detailed in many areas, but it was noticed that many times that the responsible party for the actions was negligible. For example, with regards to water analysis for washing it is unclear who has that responsibility and what actions should be taken if the wash water is found to be out of compliance.

2.7.2 Corrosion Scoring

Section 3.3.1.1.1 and Table 3-2 contain the essentials for an airman to score an AGE unit for corrosion. This could be improved with a better format that asks the airman scoring the asset, specific questions with regards to the state of corrosion on particular areas/regions on the assets. Responses to such specific questions could generate a more consistent score across the Air Force as a whole. We recommend the Marine Corps CPAC corrosion assessment checklist as a reference. Battelle could make this checklist available with consent from the CPAC PMO if the Air Force Support Equipment and Vehicles Division would like to review it.

2.7.3 Undercoating

Section 3.22 talks briefly about SE undercoating considerations. It is Battelle's belief that an undercoating program could be very beneficial for the longevity of AGE. More details as to how flights can get their AGE undercoated should be included.

2.8 Theoretical Methods to Combat Corrosion

While the earlier sections of this report discuss the observed practices at the PACAF locations and some of the practices that could be adopted from the Marine Corps CPAC program, this section provides specific recommendations that could be added to the T.O. as guidance as well as discusses potential collaboration opportunity for a CST pilot at one of the PACAF locations.

2.8.1 CST Pilot Collaboration

The Marine Corps CPAC program has a CST in Okinawa servicing their assets on the island. Within the CONUS, the CPAC program's mobile CSTs have been engaged by the Army to service some of their gear at remote locations. The Support Equipment and Vehicles Division could consider running a pilot activity with the Marine Corps and have the CST in Okinawa service the AGE at Kadena Air Base and monitor the health of the assets.

2.8.2 MIC Management – Equipment Storage and Parking

For management of MIC, it is important to understand the mechanism by which bacteria and fungi, the known primary causes of MIC get on the AGE. Almost all fungi reproduce asexually by producing spores. Spores are dispersed by moving water, wind, or by other organisms (animal feces after ingestion, insects, etc.). Spores are specifically adapted for long range dispersal as well as for survival in extreme environments, and can often survive for extended periods of time, in unfavorable conditions such as extremely high and low temperatures, UV, and areas with limited nutrients. Once conditions become favorable for growth, then the fungus will germinate from the spores.

Bacteria, while generally not as hearty as fungal species, can be spread in the same manner (wind, water, other organisms). Some types of bacteria can also form spores, offering the same protection during times of stress as the fungal spores. Another type of microorganism is termed an extremophile, an organism that thrives in physically or geochemically extreme conditions that are detrimental to most life on Earth. Two examples of these are obligate anaerobes, which can only live in oxygen-free environments (and are commonly found in MIC-prevalent areas) and radioresistant organisms, organisms that are resistant to high levels of ionizing radiation (e.g. UV).

Most AGE/SE observed during visit to the three PACAF locations was stored/parked on open lots with blacktop extending on vegetation. Grass clippings are regularly deposited on the undercarriage creating potential for MIC. Given the above understanding of how the MIC causing bacteria and fungi reproduce, the Air Force could consider including guidance on parking of equipment stored on open lots to not extend over the surrounding green spaces. Additional guidance could include a requirement that a 4 to 6 feet perimeter surrounding the storage lots be formed with gravel or other benign material void of vegetation or areas requiring lawn mowing.

2.8.3 Inclusion of LTPC in TO 35-1-3

Include application of the LTPC in Table 3-1 for maintenance, repair, and overhaul of certain assets such as generators etc. at the depot level. This could potentially be implemented at the AGE maintenance facility at the Hill AFB, UT.

LTPC coating repairs on AGE will most likely be completed as stated in Table 3-1 of the T.O. with wet coatings.