Corrosion Management – AFRL Perspectives and Activities

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ABSTRACT

Corrosion is understood to cause a significant maintenance burden on the operation of aircraft and other defense systems. Typical discussions addressing corrosion initiate with a review of the cost of corrosion, but in addition to cost, there is a compromise to system availability and, sometimes, even safety when corrosion occurs. The importance of corrosion management for United States Air Force (USAF) aircraft is exemplified by inclusion of corrosion in all five pillars in the life cycle of aircraft as mandated by the Aircraft Structural Integrity Program (ASIP) codified in MIL STD 1530Dc1. To manage and mitigate corrosion, the Air Force Research Laboratory (AFRL) has established an Integrated Product Team (IPT) that includes the Corrosion Program Office which used to be in AFRL, but now resides in the Air Force Life Cycle Management Center (AFLCMC). The objective of the Corrosions IPT is to engage in all aspects of science and technology development addressing corrosion management and prevention. These include activities on a very short time-scale, called rapid response, to developing engineering solutions, to long-term research and development programs to migrate corrosion management from the current "find and fix" to "predict and manage." Examples of engineering efforts, including testing and qualifications, plus long term research and development programs are discussed. Representative examples include improved sealing of fasteners, evaluation of alternative coating materials to current chrome-based primers, accelerated testing chambers that combine multiple effects on materials integrity, mitigation of microbiological-influenced corrosion, and developing predictive methods for corrosion as a function of the usage environment, including the potential to integrate corrosion environment and coating degradation sensors to enhance data inputs for predictive algorithms. These examples, plus additional overview material, shows the breadth and depth of current USAF activities to development new methods to manage corrosion processes and minimize their impact of aircraft safety, availability, and sustainment costs.

1.0 INTRODUCTION

The serious consideration of corrosion on the US Department of Defense is highlighted in an annual publication titled "Estimated Impact of Corrosion on Cost and Availability of Department of Defense (DoD) Weapon Systems" [1]. This publication is sponsored by the DoD Corrosion Integrated Product Team (Corrosion IPT) which was established by the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD (AT&L)) in response to Congress giving the USD (AT&L) primary responsibility for mitigating and preventing the effects of corrosion on military equipment and infrastructure. While the exact methods are not described, the study uses multiple data sources provided by each Service within the DoD to extract and estimate the impact of corrosion on the cost to maintain weapon systems, including aircraft for the US Air Force. The data sources for each service are listed in the report and, therefore, are not repeated here. In addition, the report addresses the availability of weapon systems by providing an estimate of the number of hours that weapon systems are not available due to maintenance related to corrosion. Again, the exact process by which these numbers are derived is not described, but the overall conclusion from this analysis is that corrosion has a significant cost to the DoD and impacts that availability of aircraft for the US

Air Force (USAF).

Another document that highlights the considerations for corrosion is the latest version of MIL STD 1530Dc1 [2] where corrosion is called out in all the five major structural integrity program tasks. In Task 1, Design Information, there is a sub-task that specifically identifies the need to include corrosion prevention and control (CPC). For Task 2, Design Analysis and Development Testing, there is a sub-task addressing corrosion assessment. In Task 3, Full Scale Testing, corrosion related activities are captured in the sub-task addressing climatic testing and in Task 4, Certification and Force Management Development, corrosion related processes are addressed by the sub-task of preparing a Force Structural Maintenance Plan (FSMP). For Task 5, Force Management and Execution, corrosion is again explicitly called out in the sub-task addressing the CPC plan and corrosion assessment updates. The integration of corrosion into all five tasks of ASIP indicates that actions to minimize and mitigate the impact of corrosion on the safety, availability and cost of maintenance of the USAF remains an important consideration for the safe management of USAF aircraft.

2.0 AFRL CORROSION INTEGRATED PRODUCT TEAM

The US Air Force Research Laboratory (AFRL) has a rich history in performing multiple research and development programs related to corrosion, including coatings assessment, environmental degradation testing, and standards development related to aviation and corrosion. However, with the renewed interest in corrosion related research and development activities, driven in part by the desire to eliminate the use of hexavalent chrome-based primers, AFRL stood up a Corrosion Integrated Product Team (IPT) to lead research and development activities with AFRL and provide the link to the activities of the Office of the Secretary of Defense (OSD) Corrosion and Policy Oversight Office (CPO). The mission of the Corrosion IPT is to ensure continuity in science and engineering related to corrosion, plan and execute corrosion research and development, and facilitate the transition of technology and processes to improve corrosion fighting capabilities.

In realizing this mission, the Corrosion IPT has responsibilities that extend to include the corrosion research and development activities across AFRL and to engage in other development and transition activities across the USAF. This includes close interaction with Corrosion Prevention and Control Office (CPCO) in the Air Force Life Cycle Management Center (AFLCMC) which is responsible for processes and procedures as implemented within individual System Program Offices (SPOs). However, the interaction expands to include the other Department of Defense (DOD) Services and Major Operating Commands within the Air Force. The breadth of the Corrosion IPT includes interaction with the academic community for basic research addressing corrosion all the way to providing rapid response to inquiries from specific weapon systems on questions and challenges related to corrosion. The scope of the technical efforts span topic areas that include preventing, predicting, detecting, and overall managing corrosion and how it affects the operational capabilities of the USAF assets.

To realize these objectives, the Corrosion IPT has several core members with in-depth knowledge in corrosion sciences and supplements this core knowledge with expertise from other groups within AFRL, to include the Material and Manufacturing Directorate and other Technical Directorates within AFRL. This includes sustainment of current military assets and development of new materials and designs for future systems. As the comprehensive skill set to address corrosion is quite broad, the Corrosion IPT leverages multiple organizations outside of AFRL as well. A critical attribute of the Corrosion IPT is the ability to adapt its membership as a function of need and include the "part-time" members during this time without requiring any changes in affiliation or management, making the Corrosion IPT quite agile to response to emerging corrosion concerns.

3.0 AFRL CORROSION IPT RESEARCH AND DEVELOPMENT ACTIVITIES

The AFRL Sustainment Science and Technology Strategy and AF CPC Strategic Plan identify five elements necessary to develop and implement technologies that negate the effects of corrosion on safety, cost, and system availability, and to ensure continuity in corrosion science and engineering expertise. The first is base knowledge by a core team in the areas of corrosion science, plus system acquisition and sustainment. This is addressed by the members of the Corrosion IPT. The remaining four elements include prevention, prediction, detection and characterization, and management of corrosion and are related to specific projects integrated into the current Corrosion IPT activities. The theme of these research and development activities to change the current practice of corrosion management from a traditional "find and fix" to a "predict and manage" framework. To make this approach possible, multiple aspects of the corrosion process need to be recreated and understood to facilitate the prediction of corrosion. The items that have been identified by the AFRL Corrosion IPT include the need for relativistic test coupons that represent actual assembled aircraft components, accelerated testing that integrates all factors that affect the formation of corrosion, monitoring of all environmental parameters that need to be included in accelerated testing and predictive models for corrosion formation, development of models to predict corrosion, plus methods to measure protective coatings breakdown to know when these cease to function as intended. Specific details of each of these projects are described in the following sections and is followed by a short summary of activities based on the current reactive processes for addressing corrosion.

3.1 Structural Component Corrosion Simulation

To properly test potential corrosion prevention systems, the testing process must address systems as integrated and implemented on weapon systems. Specific coatings testing protocols exists, such as the ASTM B117 standard, and are suitable to test durability of coating materials. However, the fully integrated nature of an aircraft assembly is not addressed in these testing procedures which led to developing test articles called Structural Component Corrosion Simulation (SCCS). These include features typically found in aircraft structure. To be fully representative, the SCCS sample has two configurations representing a large transport aircraft fuselage component and a small fighter aircraft wing splice, shown in Figure 3-1. The test articles include possible variations of skin alloys, stiffener alloys, splice plate alloys, fastener types, fastener alloys, and corrosion protection schemes as a function of design parameters for the test samples. The selection of the material in these test articles would be representative of the weapon system being assessed, but can also be made as generic as possible to represent the broadest range of weapon systems in a single set of testing.

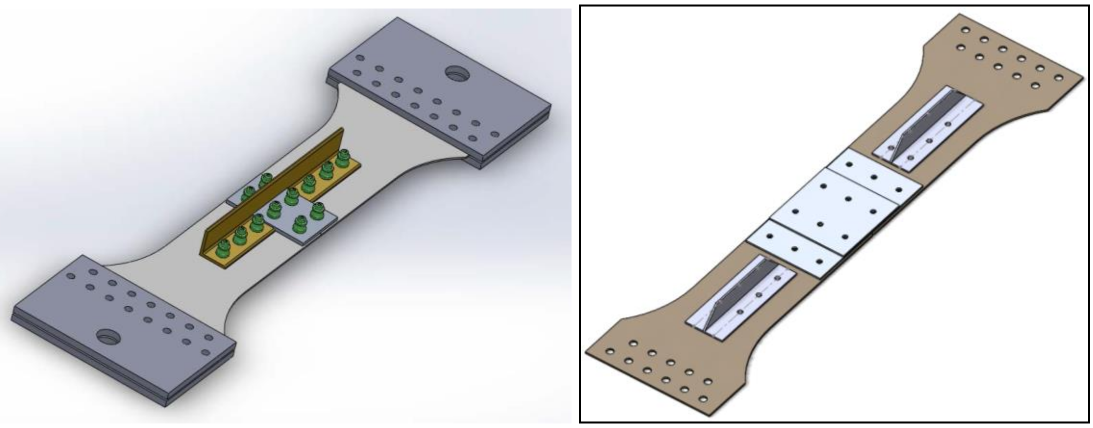

Figure 3-1: SCCS of a representative wide body fuselage (left) and a fighter wing splice (right)

Another feature of these test articles is the ability to adjust the corrosion protection scheme as a function of the testing process. For example, one set of test samples would be assembled with sealant between layers whereas another set could be assembled with sealant only along the edges of a joint. Both configurations are commonly found and the impact of selecting one over another could be determined with this test sample configuration. In addition, the test samples are designed to enable assessing multiple operational parameters as once, such as environment and loads in a combinatorial fashion. Standard maintenance processes could be introduced to represent when a component is disassembled and reassembled as part of standard maintenance practices. The test coupon configurations have been finalized and are planned to be tested in the Accelerated Combined- Effects Simulation (ACES) chamber which was the subject of a separate development program.

3.2 Accelerated Combined Effects Simulation Test Chamber

A common challenge in testing for corrosion performance of a new preventive method is combing the effects that could impact the capability. These include factors such as loads, temperature, and humidity. The goal is to develop an accelerated testing process that integrated all primary parameters that would impact the ability to prevent corrosion. Loads will need to be included in the future as they can affect the boundary conditions of any flexible coatings around fasteners and temperature and humidity can affect the kinetics of the corrosion process.

This need led to the development of the Accelerated Combined-Effects Simulation (ACES) Test Chamber. The development has taken several iterations and includes attributes of salt fog chambers and other environmental parameters, such as temperature. Target values for the final version under assembly includes temperature ranges from +150 to -61 degrees Celsius, humidity ranges from 20 to 95 percent relative humidity with potential to achieve 100 percent with a booster system. In addition, the test chamber can expose the test samples to elevated ultraviolet light and various background gases, such as ozone, carbon monoxide, and carbon dioxide, plus possible local pollution sources, including sulfuric and nitrogen-based acids. The current ACES chamber is shown in Figure 3-2.

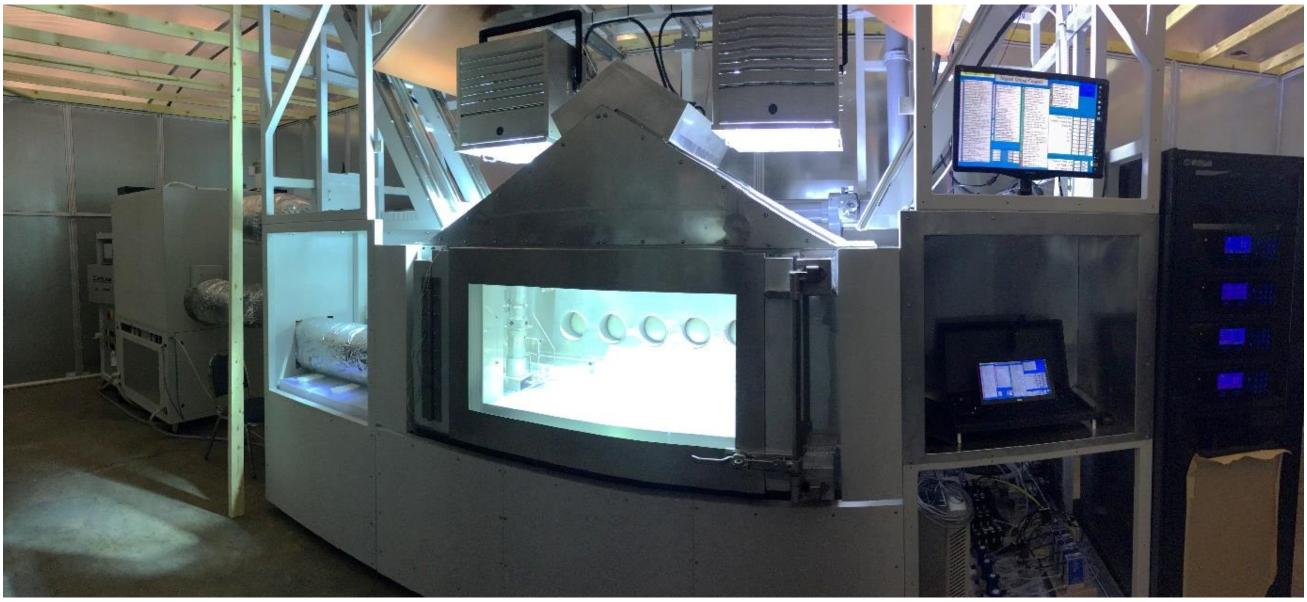

Figure 3-2: ACES Test Chamber

3.3 Weather Instrumentation and Specialized Environmental Monitoring Platform

The new capability to test combined atmospheric effects leads to the need to assess the values for such effects. Current methods to determine the Environmental Severity Index (ESI) as listed in current USAF technical data was determined form a very limited set of measurements at multiple locations [3]. ESI values were determined from mass loss measurements at several different locations. Typically, this was in the form of exposure racks where one sample per quarter was extracted and the mass loss due to corrosion was measured after a proprietary cleaning process was applied. Inconsistencies have been found in this data [3]. In addition, no independent measures of the atmospheric composition during the exposure time was taken. The constraints on the measurements of the published ESI has generated the need to capture improved metrics for the ESI values using new monitoring systems that include coupons for mass loss measurement plus the ability to measure atmospheric conditions, to include pollutants and general weather conditions that can affect the rate of corrosion. By understanding the loss as a function of environmental conditions, methods to compensate for unexpected variables, rather than simplified averages over a 3 month period, can be included in determining the effective ESI at any given location.

However, to obtain such values, a new coupon monitoring system was developed, called the Weather Instrumentation and Specialized Environment Monitoring Platform (WISE-MP). The system is shown in Figure 3-3. The system consists of a support frame and sample exposure rack, similar to previous ESI measurements, but adds a weather monitor, a particulate chloride monitor, and a multi-functional gas monitor to measure various additional pollutants. The intent of the system is to measure relevant environmental parameters and correlate them to corrosivity at a given operating location. The sensors included in the WISE-MP system enable it to measure and record temperature, humidity, wind speed and direction, and various types of pollutants, such as sulfur dioxide and nitrogen oxides, even at very low levels. To make these measurements representative, the details of the environment are captured on a more frequent basis, ideally real time if possible, and correlated to the independent mass loss measurements. In place of a single test sample, a minimum of three test samples are measured to determine their mass loss at each measurement interval. Materials in the mass loss measurements include several differing aluminum alloys, such as 2024 and 7075, representing primary structural alloys used on USAF aircraft, in addition to the previous reference materials which included steel and copper. Initial assessments will be made with uncoated test samples. With this approach, the mass loss and corrosivity are no longer based on exposure averaged over a year with a very limited number of test samples, but incorporate diurnal and seasonal variations that will affect the test coupon corrosion rate.

Figure 3-3: WISE-MP monitoring platform with the following – 1. Multi-functional gas monitor, 2. weather station, 3. particulate chloride monitoring, and 4. control box.

3.4 Corrosion Prediction

With the development of the WISE-MP enabling the impact of all environmental parameters to be measured, the potential exists to address the formation and progress of corrosion via simulation. While several corrosion modelling efforts have been completed in the past [4], these have typically been relatively simple in their scope by addressing the corrosion of bare metal in the presence of a corrosion-favorable environment, such as no protective coatings and with a high humidity. Variations in these parameters as a function of use and additional environmental parameters has had limited exploration to date. To mature modelling capabilities, two projects are being run concurrently that seek to enhance the sophistication of corrosion modelling. One is focused on predicting variable increments of damage based on diurnal and seasonal changes in humidity and temperature, plus the integration of other atmospheric contaminant on the rate of corrosion. The other modelling effort is focused on pit formation in aluminum alloys that includes surface wetness and other ground station-based data. The goal of these modelling efforts is to improve the prediction of corrosion even on bare metal, as a function of where the metal is located and the local atmospheric and environmental conditions. As both of these efforts are in their early development stages, data to correlate the modelling capability to complex conditions are not available at this time. However, preliminary data indicates both approaches should refine current predictive capabilities for bare metal test samples.

3.5 Coating / Surface Condition Assessment

To make models of corrosion fully predictive, they must include the impact of protective coatings and their eventual breakdown. This is made especially difficult as most aircraft protective coatings have at least two differing stages of protection. The first is a barrier coating, such as a polyurethane-based topcoat, that prevent the electrons to move from one metal to another. For many structures, another barrier coating is the polysulfide sealant that is found in many commercial and military aircraft as a sealant to prevent water ingress into areas and/or minimize fuel leakage. The second stage of protection is an inhibitor in the primer material that is sacrificially consumed to avoid the degradation of the metal underneath the primer. However, once the inhibitor is used, the electrochemical reaction moves to consume other metal materials.

The strategy being pursued for these degradation methods is currently based on two independent, but interlinked, measurements of the condition of coatings. One approach uses scanning Kelvin probes to measure the work function of a surface [5]. Previous work has shown these measurements can be correlated to degradation of urethane-based coating and, therefore, would provide an indication when these coatings no longer function as a barrier. In addition, a second effort is investigating the use of embedded sensors to attempt to measure properties that indicate inhibitor loss and could also indicate barrier coating breech even if the overall coating quality is still good, as can be found when the top-coat is torn rather than degraded. While the details of this measurement process are still a proprietary development, it is anticipated that results will be reported in the public domain in the near future.

3.6 Corrosion Environment Sensors

Previous work by members of the AFRL Corrosion IPT as part-time members focused on the use of embedded sensors to measure parameters in aircraft to predict the possible presence of corrosion. These sensors, commonly referred to as “corrosion sensors,” are more accurately described as corrosion environment sensors. A common practice is to use bare metal component and monitor the changes in conductivity or related property to determine if the metal is being compromised by a corrosion process that affects the ability to conduct an electrical current. Measurements systems have been developed to measure these changes in regular intervals either use equipment integrated into aircraft and/or separate and plugged into the sensor system. The challenge for these sensors is the issue of performing measures on bare metal and not including the effect of protective coatings and primers. Therefore, the sensors do not measure corrosion, but only the possible environment that would allow corrosion to occur. As an example, a recent presentation summarized an effort by Battelle Laboratories that had over 1500 sensors installed on various flying military platforms, yet there was no data that could correlate the readings of the sensors to the presence of corrosion [6]. However, the value of these sensors can be found if they are used to help guide maintenance practices, such as wash cycles, or used in testing programs to measure the effects of a testing protocol on measured parameters, such as humidity [3].

3.7 Corrosion Detection

Corrosion detection in flying military assets is commonly based on current nondestructive inspection methods, such as eddy current and ultrasound. These methods have been successfully applied to detect corrosion, and developments in the area have leverage efforts to improve nondestructive inspection of fatigue cracks and other types of damage. Various research efforts have focused on trying to accelerate the inspection for corrosion, such as using thermography and terahertz methods to detect corrosion under paint. However, to date these have not transitioned readily, usually due to the cost of implementing and supporting these new inspection methods within current operational constraints of the military services. In addition, multi-frequency eddy current methods have been investigated for detecting corrosion under very thin aluminum layers with some success, but making these methods applicable to metallic layers greater than 1.5 mm remains a challenge.

Two very recent programs have been initiated within AFRL to address corrosion on large surfaces of ground-based infrastructure and to detect damage in multi-layered structures with a total thickness of more than 1.5 mm. As these projects are in their very early stages, it is pre-mature to report any results from these efforts.

3.8 Quick Reaction / Customer Support Activities

In addition to research and development, the efforts of the Corrosion IPT include several quick reaction projects which typically last less than 6 months. Examples of these types of projects include processes to improve the application and curing time for sealants, methods to enhance the removal of moisture from inside aircraft, and methods to improve corrosion prevention compounds. These projects are typically closely coordinated with the AFLCMC CPCO and focus on engineering aspect of the solution space, such as processes and procedures for applying sealants, rather than possible research programs, such as formulating new sealants.

However, the ability to assess the impact of micro-biological agents on corrosion, especially the degradation of bio-diesels and similar biologically derived fuels, took some research in the measurement process and assessing the severity of the contamination to fully understand the degradation that occurred and the source of the contaminants. With the completion of this analysis and diagnostics, this capability is now a rapid response function to quickly take some samples of contaminate, determine the source, and prescribe the mitigation process to eliminate the contaminate and minimize its ability to compromise the performance of the fuel.

3.9 Future Research and Development Opportunities

While the current research and development portfolio of the Corrosion IPT illustrates that there are significant efforts underway, several topics are not being addressed at the moment and will require additional time and resources. Future topics of interest include addressing how the combined effects testing capability could be used to optimize coating performance on military aircraft. The feedback from the testing should be structured to provide meaningful inputs to the design and development of future coating systems. One area that could benefit from these developments is enabling improved coating performance around seams and fasteners—typically, locations where coating bridges commonly allow protective coatings to fail. In addition, the development of non-chromate coating systems is needed to protect the aluminum and steel alloys found in ground based support equipment as a complement to the current development efforts that have focused on aircraft materials applications.

Another area of interest is how atmospheric corrosion of aluminum alloys could be quantified and translated into damage metrics to enhance the management of corrosion as it impacts safety in addition to availability. This could include the development of location specific severity indices from the damage metrics. For micro-biologically influenced corrosion, it would be helpful if sensors could be developed to detect presence of microbiological elements that are linked to material degradation, ideally before any degradation has occurred. With these measurements, it would be possible to explore options to predict the degradation and as function of the microbiological elements and the environment in which they are detected. These are several areas that are of interest in the near future as the process to evolve from a “find and fix” philosophy to a “predict and manage” approach is being developed.

4.0 TRANSITION AND COMMUNICATION PATHS

Technology transition remains a challenge for any technology developer as the new capability has to show superior performance and a cost-effective implementation process. This includes the acquisition cost of the new technology and the anticipated life-cycle costs when compared to current practice. The AFRL Corrosion IPT shares these challenges with all technology developers, but has an advantage that there is a readily accessible outlet for technology development. As mentioned previously, the Corrosion IPT works closely with the AFLCMC CPCO in its activities. The same Division of AFLCMC has a mission to facilitate transition of technology to the Warfighter. The Corrosion IPT has used this venue to facilitate technology transition in addition to conventional paths through individual SPOs for weapons systems that need the technology solution to an existing challenge.

Much of the technology development efforts are shared through various national and international conferences as part of an integrated communication strategy. This includes the opportunity to harvest ideas for future research, development, and solutions that are beneficial to the USAF. In addition, the OSD CPO has several communication venues that enable sharing of ideas and concepts within the DOD. Lastly, the Corrosion IPT is using international agreements, such as NATO STO, to expand its interaction to allied military services across the globe.

5.0 SUMMARY

The AFRL Corrosion IPT was established to provide a core groups of scientists and engineers to address current and emerging needs to mitigate the effect of corrosion on USAF asset safety, availability, and cost of operations. The core team leverages a broad range of scientists and engineers across AFRL in pursuing research and development projects to address corrosion prevention, monitoring, testing, detection, and mitigation. The current research and development portfolio addresses primary gaps in testing and assessment that emerge as the USAF evolves from a “find and fix” approach to a “predict and mange” process for the enhanced management of corrosion in USAF assets. Initial efforts focus on various corrosion processes found in aircraft, but the overall mission of the Corrosion IPT includes all assets owned by the USAF, such as ground support equipment. Current efforts are components of an overall strategy, and emerging needs continue to warrant investment in corrosion mitigation technology. The Corrosion IPT has several transition paths which include leveraging the close connect with the AFLCMC CPCO. Communication of development efforts and harvesting of new ideas to address corrosion are facilitated by the OSD CPO through periodic sponsored communication forums. Thus, the efforts of the Corrosion IPT indicate promising future capabilities to minimize the impact of corrosion on the safety, availability, and cost to sustain USAF assets.

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