Predicting Corrosion in Military Aircraft

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Predicting Corrosion in Military Aircraft

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Aircraft typically comprise multiple materials, each exhibiting unique electrochemical properties. When they are exposed to harsh marine and global environments, the difference in material properties can lead to severe galvanic corrosion, causing safety risks, costly repairs, and reduced readiness.

This article shows how a new physics-based corrosion prediction software tool[1] can be used to predict, assess, and mitigate potential galvanic corrosion problems in the design phase, before aircraft are built into the weapons system. A Small Business Innovation Research (SBIR) project funded by the Office of Naval Research (ONR)[2] has already demonstrated that this new modeling approach could identify and assess the severity of several corrosion issues observed in existing aircraft systems.

Naval Air Systems Command (NAVAIR) data show that half of all aircraft depot maintenance costs are attributed to corrosion, and galvanic corrosion has been implicated as an initiator for more than 80% of fatigue issues. Mixed-metal assemblies cause galvanic corrosion, and corrosion pits initiate fatigue. People often expect increasing use of carbon fiber composites will reduce corrosion, but the opposite may happen because carbon fibers are far more cathodic than stainless steel (SS) and nearly any other metal. In addition, new materials such as low-observable sealants and gap fillers can easily cause serious and unexpected corrosion problems,[3] even between galvanically incompatible materials not in direct physical contact.

The best place to eliminate corrosion problems is in the design phase, when preventing problems being built into the weapons system at the beginning mitigates the need to fix them later in the depots. Every new weapons system must have a corrosion control plan, and every corrosion control plan addresses the issue of galvanic corrosion with reference to MIL-HDBK-729[4] and MIL-STD-889,[5] which base galvanic corrosion decisions on the galvanic potential difference between metals. The program management guide for corrosion prevention and control[6] goes further than most by combining galvanic tables from several sources and noting the importance of relative areas, but this approach is still based on rule of thumb.

The problem is more complicated than this because the galvanic corrosion rate is actually determined by corrosion current, which in turn is a complex function of materials, electrochemical properties, corroding electrolyte chemistry, and the geometry of an entire assembly that includes anodic materials such as aluminum and cathodic materials such as SS.

In the past, such a complex problem could not be addressed, but the development of new computational approaches has made it possible to predict galvanic corrosion, even for complex assemblies.

The method uses finite element analysis (FEA) to solve the electrochemical currents in an assembly by incorporating its materials, coatings, and exact design as defined in its computer-aided design (CAD) model. This is the same approach as the standard stress and heat flow models that are used to design today's aircraft, but it is considerably more accessible to the material and process and design engineer.

Predicting Galvanic Corrosion

We have investigated the risk of galvanic corrosion in several Naval mixed metal designs using GalvanicMaster[†] (now CorrosionMaster[†]), a software tool developed by Elsyca NV in Belgium for predicting galvanic corrosion locations and severity on complex assemblies of mixed materials. Details of the software have been reported elsewhere.[1]

The model requires the polarization curve in the corroding electrolyte (usually 3.5 or 5% sodium chloride [NaCl]) for each surface chemistry in the assembly (CuBe, Cd, Al, etc., and coatings such as Cd and anodizing), since this is what determines the galvanic potential and galvanic current at each location on the surface. The polarization curves are obtained following the requirements of a best practices guide developed by the ONR Sea-Based Aviation (SBA) Team.[7] Although obtaining accurate polarization curves is a time-consuming process, the curve obtained for a particular material can then be used in any number of galvanic corrosion predictions, just as the stress-strain curves for an alloy can be used in any number of stress analyses.

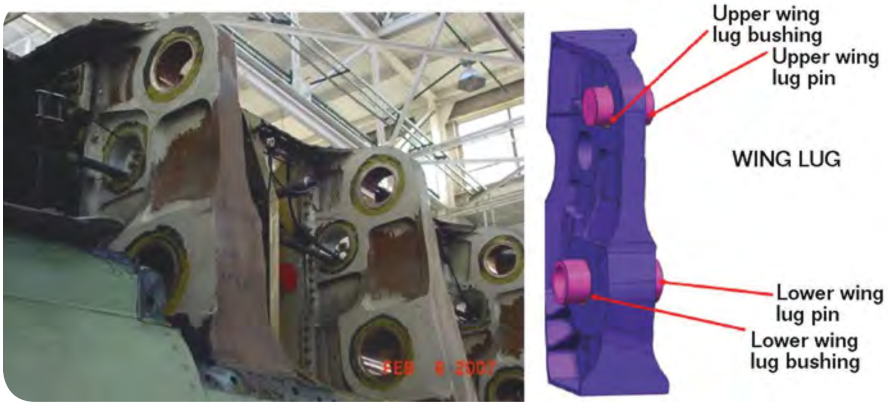

FIGURE 1 Corrosion in F-18 wing-fuselage attach bulkheads.[8]

The result of the calculation is displayed as a color overlay on the CAD model showing galvanic current, galvanic potential, or corrosion rate at each point on the surface. Different surfaces in the CAD model can be "turned on or off" to understand the sources of the corrosion current at any location. This makes it possible to predict the expected galvanic corrosion locations and severity, as well as understand the contributions from different components, which will help to better mitigate the problem.

Although this approach is a big step forward, it is not perfect since it only tells us the corrosion rate at corrosion initiation and does not yet incorporate high-impedance coatings such as paints. The software is being developed to address these limitations; nevertheless, even now it is a very useful advance over the previous rule-of-thumb approach.

Predicting Airframe Corrosion at Bushings

When bushing materials such as CuBe or SS are inserted into aluminum airframe holes, the standard practice is to plate the bushing with Cd for galvanic compatibility. It is also common to anodize the aluminum

† Trade name.

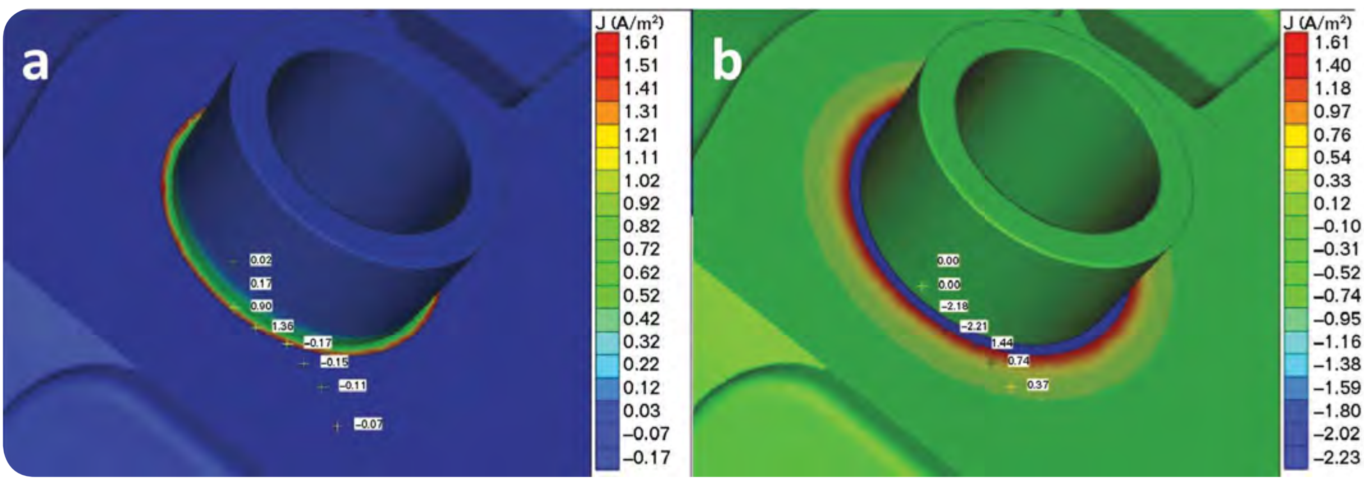

FIGURE 2 Corrosion currents for the wing lug assembly: (a) anodized Al, Cd-plated CuBe, and steel; (b) anodized Al, bare CuBe, and steel.

surface to provide the best possible corrosion resistance. The nonfunctional surfaces of bushings and the surrounding aluminum are almost always painted, with sealants used at interfaces to try to minimize water ingress and corrosion. Despite all of these precautions, it is very common to see corrosion of aluminum lugs caused by galvanic interaction with bushings.

We have used the software tool to evaluate corrosion of the aluminum airframe in the vicinity of the wing attachment bushing on the F-18, where corrosion is frequently seen (Figure 1).[8] The 7050 aluminum (UNS A97050) has a CuBe bushing that surrounds the PH13-8Mo SS (UNS S13800) pin that attaches the wing. Polarization curves were measured for the materials and coatings in an electrolyte of 5% NaCl. The aluminum is anodized, while the CuBe is Cd-plated, and all nonfunctional surfaces are primed and painted with an approved chromate material. Why then, do we still see corrosion around the bushings?

First, we know that paint systems are imperfect, porous, and easily damaged, and that galvanic differences are a strong driver. Therefore, as a first step we can analyze the system as though it were not painted. We know that aluminum and cadmium are galvanically compatible, which is why the bushing is Cd-plated.

Because galvanic modeling allows us to predict both the galvanic currents and the resulting corrosion rates, however, we see that the more cathodic anodized layer on the aluminum galvanically attacks the Cd on both the CuBe and the pin, with the highest corrosion adjacent to the aluminum (yellow and red areas in Figure 2[a]). Predicted currents are shown at various locations, with positive current indicating corrosion and negative indicating source of corrosion.

Note that the current (and hence the corrosion) is highest on the Cd at the interface with the anodized Al, but that the Cd is attacked along the pin as well. This illustrates that galvanic attack works at a distance, not just at a direct interface, which is why metal-filled sealants and gap fillers can galvanically attack aluminum airframes not directly attached to them. Once the Cd is damaged, the CuBe is exposed, and the much more cathodic CuBe can now attack the anodized aluminum. The highest corrosion is at the interface adjacent to the CuBe, but reaches out across the Al surface (CuBe is blue and the attacked anodized aluminum is represented by the yellow and red areas in Figure 2[b]).

Conclusions

Computational galvanic corrosion prediction is still in its infancy, but even at this stage it can be a powerful tool that enables us to do several things that we were unable to do previously:

- Predict where corrosion will occur and its relative severity, even in a complex galvanic assembly where the galvanic couples are not directly connected.
- Predict which items in a mixed-metal assembly will corrode, as well as the items that will cause that corrosion. This allows us to identify unexpected galvanic interactions.
- Predict unexpected corrosion sequences, such that a coating designed to prevent corrosion on one component (the Al lug) can actually cause corrosion on another (in this case the Cd coating), risking sequential degradation of different materials.
- Test any number of material, coating, and design options to mitigate the problem without having to go through the expensive and time-consuming task of manufacturing and corrosion-testing actual assemblies. Galvanic corrosion prediction is a faster way to solve problems at a greatly reduced cost.

Acknowledgments

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