Corrosion Management at Dassault-Aviation
Challenges & Perspectives

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ABSTRACT

Starting from illustrated in-service experience, corrosion root causes will be summarized. One of the most challenging aspect concerning structures made out aluminum alloys is the Chrome free alternatives development to maintain the same corrosion protection and industrial efficiencies. The de-risk process will be presented. It will first discuss lab tests and their poor representability with in service corrosions. Then flight experimentations feedback will be discussed. The third aspect for the de-risk approach is to assess a better knowledge of the real corrosive environment seen by each aircraft and set the basis for an adaptive maintenance. It could combine sensors and big data analysis for corrosive environment monitoring 24 hours a day.

1.0 IN SERVICE CORROSION

Because of our dual business model, business jets and fighters aircraft, our particular challenge is to select industrial solutions to satisfy all our productions, including our Navy version of Rafale exposed to a very severe corrosion environment. Compared to business jets, the following specificities of such fighters are key factors for corrosion prevention :

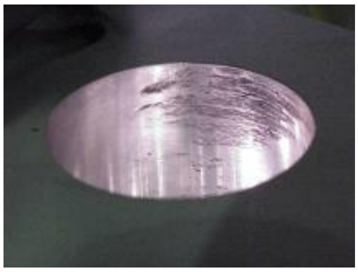
- More severe marine environment
- Very little flight hours
- More heterogeneous materials (aluminum, carbon, Radar Absorbing Materials)
- Compatibility with temporary protection
- Higher fatigue loads
- Higher temperature (supersonic)
- Higher conductivity/corrosion requirements (systems density)
- Compatibility with maintenance

First, it is important to underline that among in-service airframe damages (wear, accidents, cracks and delamination, corrosion), corrosion represents almost 50% of the number of open affairs.

With the state-of-the-art protection systems, validated over more than 30 years of experience and mainly based on chromated solutions, the corrosion root causes are most of the time the result of a weakness in the design (due to compromise) or manufacturing:

- Inappropriate design with respect to a galvanic risk, metallization
- Insufficient drainage
- Mis-evaluation of the threat (humidity versus temperature) for a given bay
- Manufacturing defects
- Lack of temporary protection



During service life, the following aspects can also degrade the situation:

- Impacts that degrade the protection
- Long storage periods with inappropriate cocooning actions
- Underestimated corrosive environment with respect to an operational location
- Difficulty to apply the proper maintenance, lack of temporary protection
- Fuel contamination

The corrosion management policy is still clearly based on “Find-it, Fix-it”. There is no damage tolerance approach available, linked to the today very weak corrosion growth modelling on specific aircraft aluminum with their real protection system.

2.0 CHROME FREE CHALLENGE FOR AIRFRAME DURABILITY

One of the most challenging aspects concerning structures made of aluminum alloys is certainly the Chrome free alternative solutions development to maintain the same corrosion protection and industrial efficiencies. Dassault-Aviation is totally committed to eliminate hazardous substances. This activity is performed in a very collaborative way, since all the airframe manufacturers rely on the same worldwide supply chain.

The overall corrosion situation is somehow accepted by the operators. It mainly relies on:

- Corrosion protection systems validated after 30 years of improvement and retex
- Resort to temporary protection
- Maintenance practice

Figure 1 shows the current protection system and suggests the chrome free alternatives under investigation.

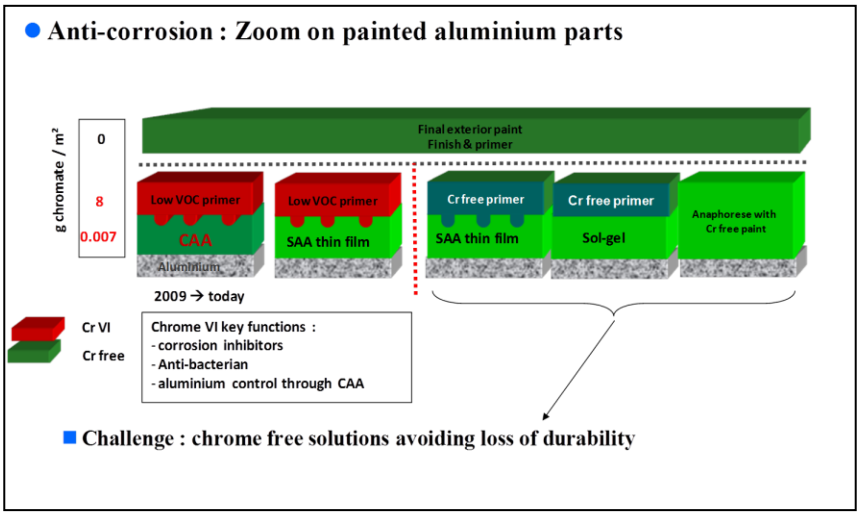


Figure 1 : Corrosion protections of aluminium painted parts

The major challenge is to replace chromates in the primer. In parallel to their corrosion inhibition role, chromates can also act as anti-fungi agents. A remaining important question however is about their effective action in fuel tanks. As illustrated in Figure 2, bacterial pollution and biofilms may be present with today's chromated protection.

Figure 2 : bio contamination example

3.0 DE-RISK PROCESS

Risk mitigation is a key issue prior to the switch to Chrome free primer, as potential degradation of durability performance, which could result in increase of time consuming maintenance. Problems may appear after the first years of operation following delivery of a significant number of aircraft..

A first axis of development is to develop lab tests that are more representative of aircraft structures in-service corrosion. These tests will have to be supported by atmospheric exposure experience.

Today, long term flight experiments of Chrome free solutions seem mandatory prior to switch to a new solution for primary parts protection.

Finally, the corrosive environment seen by each aircraft is also not well known. By comparison in structural parts justification, the fatigue load spectrum is an input for the design with available fracture mechanics models for the damage tolerance approach. In the field of corrosion resistance, neither the environmental spectrum nor the model for initiation and propagation are available. Therefore, our roadmap includes some developments to monitor the corrosion environment with the target to propose an adaptive maintenance approach.

3.1 LAB TESTS

Lab tests are of course the first step for screening of various Cr free primers behaviors. The table 1 gives the variety of corrosion inhibition principles that are under investigation.

Table 1 : Variety of Cr free primer inhibition principles

Composition	Mechanism
Zinc Phosphate	Precipitation on cathodic sites
Al Polyphosphate	Idem with higher solubility
Ion Exchange	H+ exchange, Ca leaching
Mg and Li salt	Cathodic reaction inhibition

Taking into account the wide number of combinations with surface treatments (anodizations, solgel), there is a real need for accelerated tests for primer selection. Today typical procedure is to combine salt spray exposure with representative structural assemblies:

- salt spray with scratch
- adhesion after immersion and cycling hot/wet/cold
- filiform corrosion
- galvanic corrosion
- in-house combined ageing : mechanical fatigue on lap joints, thermal choc, UV, salt spray

As illustrated on figure 3, the corrosion performances of the whole protection system (surface treatment + primer) are the result of 3 drivers. The salt spray exposures mainly characterize the corrosion inhibitors lixiviation ability to stop the degradation within a scratch. It is the reason why an ACET protocol (Accelerated Cyclic Electrochemical Test - ISO 17463) has been adapted to aluminum in order to assess the barrier and interface performance (reference: SURFAIR may 2018). Figure 4 shows that the in-service pitting morphology has been reproduced by the ACET test. It is key as the protection systems act mostly on pitting resistance mechanism. It is seen as a very rapid methodology to compare the corrosion behaviour of global protection system, where improved interface and barrier properties may compensate the lower inhibition properties associated to Cr free primers.

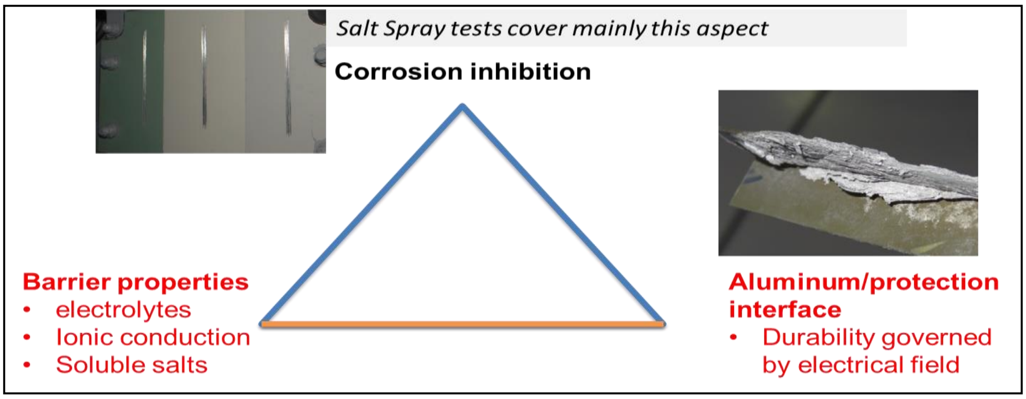


Figure 3 : global protection system vs corrosion drivers

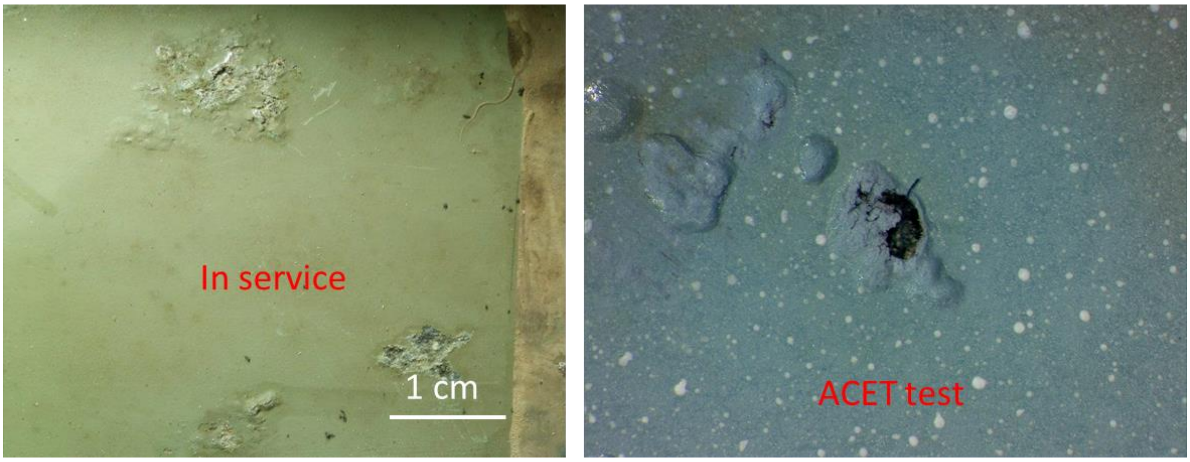


Figure 4 : Similar corrosion pits

3.2 FLIGHT TESTS

Flight experiments over a minimum period of 3 years are key for new solutions de-risking. They are systematically combined with environmental sensors to correlate with environmental severity seen by a particular aircraft (see figure 5).

Figure 5 : sensors installation to monitor corrosion severity during new protections experiments

Table 2 gives an overview of some running flight experiments.

Table 2 : running flight experiments

Aircraft	Parts	Cr free alternatives tested	Statement
Super Etendard - 2 A/C 	Fairings,doors, brackets	Unsealed SAA + PPG PSE 039 CF primer Repair : Sol-gel B0202+ PPG PSE 039 CF primer	End of experiment in 2015 after ~ 2 years on French Carrier → no corrosion, no erosion, some blisters similar to reference paint scheme
ATL2 marin patrol - 10 A/C 		Unsealed SAA + PPG CA7049, CA7521 CF primer Repair : Sol-gel B0202 + PPG CA7049, CA7521 CF primer or PPG CA7530 CF « wash-primer »	In progress, no corrosion after 5 years
Rafale – 5 A/C 	Access doors	Unsealed SAA + PPG CA7521 or Mapaero EPD3 CF primer Anaphoretic PPG Ecoating Repair : Sol-gel B0202 + CA7521 CF primer or PPG CA7530 CF « wash-primer »	In progress, no corrosion after 2 years

3.3 ADAPTIVE MAINTENANCE PERSPECTIVES

The third aspect for the de-risk approach is to assess a better knowledge of the real corrosive environment seen by each aircraft and set the basis for an adaptive maintenance.

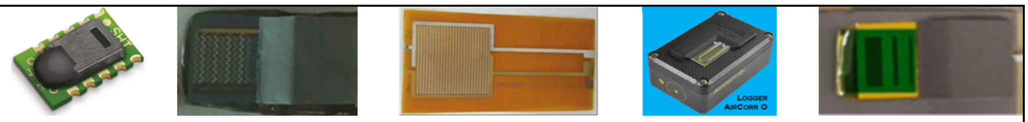
Nowadays, the recurring periodic maintenance (rinsing and temporary protection) are mainly defined according to the main location of the aircraft using STANAG 4370 world climate zoning. Part of the decision is subjective. By monitoring 24 hours a day the corrosive severity, that a particular aircraft is really facing, the periodicity and the level of maintenance could be adapted. The first objective is to base the level of recurring maintenance operations to be performed, on real corrosive environmental data.

Through several aircraft instruments (see figure 6 for equipment description and figure 5 for aircraft installations), the objective is to collect enough data to calibrate an EI (Environmental Index) as described below. It is a combination, of direct corrosive parameters measurement, with data analysis of atmospheric pollutants cartographies by coupling with the aircraft position. Big data approach is going to be used to accelerate the calibration based on past available aircraft corrosion history.

$$\text{Environmental Index} = \int (T°, HR, \text{Pressure}, \text{water}, pH, \text{pollutant } (NO_x, SO_x), NaCl)\, dt$$

- On board sensors
- GPS + world pollutant mapping

In parallel, some development efforts still address the calibration of direct corrosion sensors, which could provide an alert for a maintenance operation.



Parameter	sensor	Today
Temperature & humidity	Sensirions SHT15	flying
water	TOW BAé	flying
Pollutants		GPS+world pollutants mapping
Ions chlorure		GPS+world pollutants mapping
Direct corrosion sensitivity	Aircorr	To be calibrated
	Sentinel	To be calibrated

Central of acquisition (independent of the aircraft system)

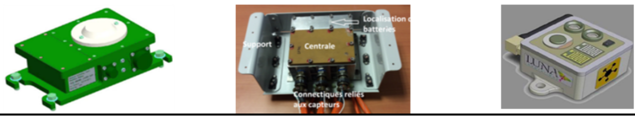


Figure 6 : sensors and equipement for corrosive environment monitoring

4.0 CONCLUSION

The Cr free challenge is seen as an accelerator to develop more representative lab tests of in-service corrosion on real airframes, and, to better characterize the corrosive environment really faced by each aircraft. This last point should lead to the first step of “adaptive maintenance”, where maintenance operations will be launched according to a corrosive environment index. From an aircraft designer and manufacturer point of view, the corrosion protection requirements for systems and equipment have to be aligned with airframe standards.