Corrosion of Aluminium Alloys in Military Aircraft

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Aluminium alloys remain essential in military aircraft because they combine low weight, high strength, reliability, and a well-understood structural behaviour. However, they are inherently vulnerable to corrosion. In service, corrosion is promoted by contact with dissimilar materials such as carbon fibre reinforced composites, by microstructural heterogeneity, and by aggressive environments including chlorides, cyclic humidity, and operational contamination. As a result, corrosion affects not only materials performance, but also flight safety, operational readiness, system availability, and maintenance costs.

In aerospace applications, aluminium alloys are typically protected by organic coating systems applied over pretreatments such as anodic layers or conversion coatings. These systems have traditionally relied on chromate-based inhibitors, which provide excellent corrosion protection but are also toxic and carcinogenic. Replacing chromates with environmentally safer alternatives, without compromising durability and airworthiness, is therefore a major challenge.

Meeting this challenge requires a deeper understanding of corrosion and of the long-term degradation and failure of protective coating systems. It is necessary to clarify both the protective mechanisms and degradation pathways of existing coatings, and to determine how alternative inhibitors interact over time with coatings and aluminium substrates. Such understanding is essential for the development of effective new protection strategies.

These strategies must also be validated experimentally. Yet aircraft service lives extend over decades, while qualification programmes depend on accelerated testing. Because acceleration can alter degradation mechanisms, laboratory results do not always represent in-service behaviour well. A key scientific challenge is therefore to translate mechanistic insights from simplified and accelerated experiments to the complexity of operational environments.

This challenge was central to the underlying PhD research. The work focused on long-term coating degradation, the protective performance of coating systems over aircraft service life, and the limitations of chromate-containing systems. It also initiated research on improving the relevance of test methods and on detecting early signs of coating degradation before major functional failure occurs.

Current and future research is directed toward predictive corrosion science: predicting corrosion across different time scales, validating chromium-free systems for severe military environments, identifying reliable early indicators of coating failure, and integrating inspection, sensing, mechanistic understanding, and AI-assisted modelling into predictive corrosion frameworks.