Chapter 1 – INTRODUCTION

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1.1 INTRODUCTION

Corrosion and corrosion fatigue in aircraft structures have been around for as long as the aircraft themselves. Various agencies of NATO have recognized this for almost as long, and interest has grown as recognition of the consequences of corrosion has increased. Corrosion was a major preoccupation of AGARD (Advisory Group for Aerospace Research and Development) since at least the mid-1970s and a major effort was made by the Structures and Materials Panel in the early 1980s. In 1985 the first of several publications appeared in the form of AG-278, AGARD Corrosion Handbook Volume 1, Aircraft Corrosion: Causes and Case Histories [1]. It was assembled by authors from Canada, The Netherlands and the United States but virtually all NATO member nations of the day contributed to the contents. However, the major credit for it should go to Mr. Tom Kearns of the United States since he understood, better than most, the enormous cost of corrosion in terms of operability and availability of equipment as well as direct financial outlays associated with repair and maintenance. He also understood the scientific and engineering complexities associated with the chemistry and physics of corrosion, as well as the challenges related to detection and quantification of damage, corrosion control and fleet management, damage repair and design for avoidance. He was the driving force for most of the early effort.

1.2 THE LAST 25 YEARS

While there was widespread recognition of the challenges posed by aircraft corrosion in 1980, there were few systematic programs in the NATO member nations designed to deal with the many problems associated with it. AG-278 had one primary goal and that was to alert those involved with the operation and maintenance of aircraft to the dangers of corrosion. Most member nations shared their experiences by providing practical case histories of corrosion related structural failures, and they explained the corrective measures that had been taken to return equipment to service. The authors of that publication would like to think that it has assisted maintenance personnel to recognize and address similar problems over the ensuing 25 years. In addition to the case histories, this early publication provides simple descriptions of the common airframe structural alloys in use at that time as well as the main forms of corrosion affecting them, namely; uniform corrosion and erosion, galvanic corrosion, pitting, crevice and filiform corrosion, intergranular and exfoliation corrosion, fretting corrosion, hydrogen embrittlement, stress corrosion cracking, corrosion fatigue, and microbiological corrosion.

The handbook may have done more than was expected since it is clear that the past 25 years have seen a dramatic increase in activity leading to a much better understanding of corrosion and particularly of the ways it contributes to the nucleation and growth of cracks, and how it interacts with mechanically induced cracks to pose threats to aircraft structural integrity. The very earliest thoughts on corrosion revolved around the simplistic recognition that it would cause thinning of structural materials, and that this thinning would cause increases in stresses on a macroscopic scale, thus contributing to instabilities in the form of buckling, crack nucleation and accelerated crack growth. As understanding increased and the mechanisms and consequences of pitting were better elucidated it was recognized that pits themselves would act as stress concentration sites and would behave as cracks. Indeed at some point they would be better described as cracks and would continue to grow by purely mechanical means as opposed to growth by dissolution of

metal at their tips. This would happen even in the unlikely event that all environmental drivers to crack growth could be excluded.

Basic research on fatigue, in both inert and corrosive environments, soon showed that fatigue crack growth rates would be accelerated by the presence of chemically aggressive species, and thus the challenging field of corrosion fatigue emerged. The influence of these mechanical and environmental interactions on structural integrity was clearly a concern, but how to manage them in any aircraft structural integrity program remained uncertain. The dilemma gave rise to much debate on whether corrosion was strictly an economic issue or also a safety issue, and if the latter, how to deal with it.

Through years of practical operating experience and a few disasters it became clear that general and localized corrosion, corrosion pitting, exfoliation and crack nucleation and growth were frequently found on or below the hidden faying surfaces of lap joints and most often at fastener holes in built-up structures. The challenges of detection and quantification of damage rapidly became apparent. Also, it was soon realized that stresses would not only increase due to metal thinning and concentration effects at the base of pits, but also because the conversion of metal to metal oxides or hydroxides would involve substantial volumetric increases. The growing corrosion products would force sheet metal in faying surfaces apart, constrained only by the rivets or bolts holding the sheets together. Distortions between the fasteners would be plastic and therefore permanent. Thus complex stress distributions would arise that certainly had not been taken into account in any early airworthiness assessments.

Corrosion in aircraft structures is clearly a complex process and the more is learned about it the more we realize that understanding how to manage it to ensure flight safety is a challenge of enormous proportions. A widespread view has emerged that corrosion cannot be dealt with in isolation, but must be considered as part of a complex set of issues affecting structural integrity and safety. Several groups have explored the concepts of holistic structural integrity processes or HOLSIP, and have reached the point where it is being applied as a logical extension of ASIP. Here, knowledge gained of the way environmental variables interact with mechanical variables to drive the nucleation and growth of cracks is being combined with conventional elastic and plastic fracture mechanics and the concepts of damage tolerance in both deterministic and probabilistic approaches.

This present document reviews some of these developments with particular attention to work carried out since the publication of AGARD AG-278, and with emphasis on how to keep aircraft flying safely when exposed to aggressive environments. No attempt has been made to provide a complete and comprehensive description of aircraft corrosion but the report provides examples of some of the main forms of corrosion found in aircraft structures and it provides examples of best practices in detection, inspection, repair and avoidance. The opening chapter (Chapter 2) provides a summary of terminology and definitions in current use related to corrosion with emphasis on the types of discontinuity present in aircraft materials as well as those created by corrosion. It also covers the concepts of crack nucleation and propagation and crack instability. It draws heavily on the work of the American Society for Testing and Materials (ASTM), an organization that has provided leadership on an international basis. The third chapter provides an indication of the costs of corrosion obtained through a systematic survey carried out over several years in the United States, but many readers will find the methodology used in the study to be at least as useful as the results themselves. However, the main focus of the report is the application of holistic methods of life assessment of aircraft structures affected by both mechanical and environmental damage, and it reviews all the related technologies needed to apply these methods both in laboratory studies as well as operational aircraft.

Several chapters have been provided in groups to focus on common themes; thus several contributions are included dealing with each of the following:

- The morphology of corrosion as it appears in aircraft structures.
- Methods of simulating corrosion damage in materials and built-up structure typical of aircraft design.

- Impact of corrosion on aircraft structural integrity.
- Practical case histories of corrosion in aircraft components and structures and particularly of the application of holistic methods in the assessment of structural integrity in the presence of corrosion.
- Means of detecting corrosion non-destructively, including one chapter that deals with radiometric methods for detection of damage, including ingress of moisture into the cavities of composite honeycomb structure.
- Corrosion prevention or avoidance.

In short, the report covers many of the practical aspects of corrosion that have been discussed above but some important topics have been passed over. For example, corrosion preventative compounds are vital in the fight to impede corrosion but an excellent review has been published fairly recently and its contents are still very much applicable today. This is TTCP Technical Report, "Effective Use of Corrosion Preventative Compounds (CPCs) on Military Systems" [2]. It considers how to use CPCs effectively and assesses the range of commercially available CPCs of the participating countries in different environments. A related report on Chemical Inhibitors has also been published recently by TTCP as MAT-TP6, TR MAT-TP-6-4-2008. These reports are readily available to Canada, the United Kingdom and the United States and they might possibly be available to other NATO member nations through appropriate channels. Also, nothing has been provided in the present report on corrosion sensors and these are clearly important in at least two ways. Firstly, sensors are needed to detect the onset and growth of corrosion damage in structures while others are important in terms of characterizing and monitoring the severity of the corrosive environment that individual aircraft see. The latter are likely to become increasingly important as HOLSIP concepts become more firmly established and require accurate descriptions of the environments to which individual aircraft have been exposed.

1.3 REFERENCES

[1] Wallace, W., Hoeppner, D.W. and Kandachar, P.V., "AGARD Corrosion Handbook Volume 1, Aircraft Corrosion: Causes and Case Histories", AGARDograph No.278, Neuilly-sur-Seine, France, July 1985.

[2] Beatty, J., Placzankis, B., Martin, B.J., Purdie, T. and Shaw, P., "Effective Use of Corrosion Preventative Compounds on Military Systems", TTCP Technical Report, Operating Assignment 37, The Technical Cooperation Program, MAT-TP-1-5-2008.