



AEROSPACE INFORMATION REPORT

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Environment Spectra and Corrosivity Monitoring Using Electrochemical and Electrical Resistance Sensors

RATIONALE

Corrosion prevention and control is an important part of aircraft maintenance, especially for those aircraft that operate in aggressive coastal environments. Improvements to corrosion prevention and control processes necessitate an understanding of the environmental severity and cumulative exposure that aircraft experience. Recent advancements in sensing and monitoring systems allow for individual aircraft tracking of environmental parameters and corrosivity. Quantitative measurements of environment spectra and corrosivity at specific positions within individual airframes can be used to determine the influence of seasonal climatic conditions, local weather, operations, storage, and maintenance activities on aircraft corrosion for optimizing aircraft corrosion maintenance and control. These time-based records of environment spectra and corrosivity for improved maintenance would support reduced operational costs and increased aircraft availability. This document is focused on aircraft, but the technologies and approaches described in the report may apply more broadly to transportation and infrastructure.

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1. SCOPE

This SAE Aerospace Information Report (AIR) provides guidance on using environmental, electrochemical, and electrical resistance measurements to monitor environment spectra and corrosivity of service environments, focusing on parameters of interest, existing measurement platforms, deployment requirements, and data processing techniques. The sensors and monitoring systems provide discrete time-based records of (1) environmental parameters such as temperature, humidity, and contaminants; (2) measures of alloy corrosion of the sensor; and (3) protective coating performance of the sensor. These systems provide measurements of environmental parameters, sensor material corrosion rate, and sensor coating condition for use in assessing the risk of atmospheric corrosion of a structure. Time-based records of environment spectra and corrosivity can help determine the likelihood of corrosion to assess the risk of corrosion damage of the host structure for managed assets and aid in establishing maintenance intervals and processes.

Diagnostics for determining damage to a structure and prognostics for predicting the remaining useful life before reaching a critical corrosion damage threshold are not within the scope of this document. Also not within the scope of this document are other nondestructive evaluation tools or structural health monitoring (SHM) technologies that can directly assess corrosion-based damage. While this document is focused on air-vehicle environments, many of these topics would translate to other industries and systems without much modification.

1.1 Purpose

The purpose of this document is to describe available environmental, electrochemical, and electrical resistance sensor technologies and techniques for onboard air-vehicle environment spectra and corrosivity monitoring, along with outlining data processing and handling methods. This document provides a system-level approach, covering sensor selection, data management, data reporting, and deployment.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR6245	Perspectives on Integrating Structural Health Monitoring Systems into Fixed-Wing Military Aircraft
AIR6892	Structural Health Monitoring Considerations and Guidance Specific to Rotorcraft
AIR6900	Applicable Aircraft Integrated Vehicle Health Management (IVHM) Regulations, Policy, and Guidance
AIR7999	Diagnostic and Prognostic Metrics for Aerospace Propulsion Health Management Systems
ARP6275	Determination of Costs and Benefits from Implementing an Integrated Vehicle Health Management System
ARP6290	Guidelines for the Development of Architectures for Integrated Vehicle Health Management Systems
ARP6407	IVHM Design Guidelines
ARP6461	Guidelines for Implementation of Structural Health Monitoring on Fixed Wing Aircraft
ARP6803	IVHM Concepts, Technology and Implementation Overview
ARP6883	Guidelines for Writing IVHM Requirements for Aerospace Systems

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

- ASTM B826 Standard Test Method for Monitoring Atmospheric Corrosion Tests by Electrical Resistance Probes
- ASTM D1654 Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments
- ASTM G1-03 Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens
- ASTM G59-97 Standard Test Method for Conducting Potentiodynamic Polarization Resistance Measurements
- ASTM G96-90 Standard Guide for Online Monitoring of Corrosion in Plant Equipment (Electrical and Electrochemical Methods)
- ASTM G102-89 Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements

2.1.3 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

- AC 43-4B Corrosion Control for Aircraft

2.1.4 ISO Publications

Available from International Organization for Standardization, ISO Central Secretariat, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, Tel: +41 22 749 01 11, www.iso.org.

- ISO 9223 Corrosion of metals and alloys - Corrosivity of atmospheres - Classification, determination and estimation.
- ISO 9225 Corrosion of metals and alloys - Corrosivity of atmospheres - Measurement of environmental parameters affecting corrosivity of atmospheres
- ISO 9226 Corrosion of metals and alloys - Corrosivity of atmospheres - Determination of corrosion rate of standard specimens for the evaluation of corrosivity
- ISO 22858 Corrosion of metals and alloys - Electrochemical measurements - Test method for monitoring atmospheric corrosion

2.1.5 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

- DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

2.1.6 AMPP Publications

Available from Association for Materials Protection and Performance, 15835 Park Ten Place Houston, Texas 77084, Tel: 800-797-6223, www.ampp.org

- AMPP TM21449 Continuous Measurements for Determination of Aerospace Coating Protective Properties

2.1.7 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

DOT/FAA/TC-16/13 Requirement for Corrosion Prevention and Control Program Study

MIL-PRF-32239 Performance Specification: Coating System, Advanced Performance, For Aerospace Applications

MIL-STD-810 Test Method Standard, Environmental Engineering Considerations and Laboratory Tests

MIL-STD-889 Standard Practice, Dissimilar metals

MIL-STD-1530 Aircraft Structural Integrity Program (ASIP)

MIL-STD-3063 Rotorcraft Structural Integrity Program (RSIP)

TO 1-1-691 Cleaning and Corrosion Prevention and Control, Aerospace and Non-Aerospace Equipment

2.1.8 Other Publications

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2.2 Definitions

CORROSION PENETRATION: Distance between a corroded surface or feature of a metal and the original metal surface.

CORROSIVITY: The corrosion response of a surrogate material sample or sensor used to infer damage to a structure or assess the severity of an environment.

ELECTRICAL RESISTANCE SENSOR: Element for measuring corrosion involving measurement of the ratio of the potential difference along a conductor and the current through the conductor.

ELECTROCHEMICAL SENSOR: Element for measuring corrosion involving anodic and cathodic reactions and solution properties.

ENVIRONMENTAL SEVERITY: The corrosion aggressiveness of an environment that is determined by either environment spectra or corrosivity measurements to provide a comparison or classification.

ENVIRONMENT SPECTRA: Time-dependent parameters that determine the corrosion aggressiveness of an atmosphere;

these parameters typically include temperature, relative humidity, and contaminants.

INTERDIGITATED ELECTRODE: Electronic conductors that are interleaved like fingers.

SOLUTION RESISTANCE: Ratio of electrode potential increment to the corresponding current increment dependent on solution.

ZERO RESISTANCE AMMETER: Instrument used for current measurement between two electrodes with no potential drop between them.

2.3 Symbols and Abbreviations/Acronyms

2.3.1 Symbols

ρ	resistivity
β_a	anodic Tafel slope
β_c	cathodic Tafel slope
ΔE	change in potential
Δi	change in current
A	area
A_1	constant
AH	absolute humidity
B_1	constant
D_T	dew point temperature
e_s	saturation water vapor pressure
h	thickness or height of electrical resistance sensor trace
I	current
I_{corr}	corrosion current
i_{corr}	corrosion current density
k	constant
L	length
n	constant
R	resistance
r_{corr}	mass loss rate
R_{fn}	reference sensor resistance at a given time
R_{fo}	initial reference sensor resistance

R_n	corrosion sensor resistance at a given time
R_o	initial corrosion sensor resistance
R_p	polarization resistance
r_t	thickness loss rate
R_v	gas constant for water vapor
T	temperature
t	time
T_a	air temperature
V	voltage across corrosion sensor
V_f	voltage across reference sensor
w	width

2.3.2 Abbreviations/Acronyms

A4A	Airlines for America
AH	absolute humidity
AIR	Aerospace Information Report
AMPP	Association for Materials Protection and Performance
ANSI	American National Standards Institute
ARP	Aerospace Recommended Practice
ASIP	Aircraft Structural Integrity Program
ASTM	ASTM International
BIT	built-in-test
CBM	condition-based maintenance
CONOPS	concept of operations
CPC	corrosion preventive compound
CPCP	corrosion prevention and control program
DAL	development assurance level
DOT	Department of Transportation
ER	electrical resistance
FAA	Federal Aviation Administration
IC	integrated circuit

IDE	interdigitated electrode
ISO	International Organization for Standardization
IVHM	integrated vehicle health management
LMI	Logistics Management Institute
MSG	Maintenance Steering Group
NDI	nondestructive inspection
NOAA	National Oceanic and Atmospheric Administration
NTC	negative temperature coefficient
RH	relative humidity
RTD	resistance temperature detector
SHM	structural health monitoring
SVHC	substances of very high concern
V&V	verification and validation
WS	weather station
ZRA	zero resistance ammeter

3. INTRODUCTION TO ENVIRONMENT SPECTRA AND CORROSIVITY MONITORING

Aircraft are exposed to a wide range of climates globally and experience dynamic environmental conditions that can cause corrosion due to weather, operations, and anthropogenic and naturogenic chemicals and contaminants. These time-dependent parameters are encompassed in the environment spectra that drive the corrosion degradation of aircraft. Parameters that constitute environment spectra may include temperature, relative humidity, and contaminants. The environment spectra will vary based on geographic location, operations, weather, and position within the airframe. Aircraft subsystems and components, including the structure, avionics, electrical wiring and interconnects, hydraulic, mechanical, and propulsion systems, are all impacted by environment spectra and corrosion degradation. The response of aircraft systems and components to environment spectra is dependent on design parameters including alloys, material combinations, protective coatings, seals, air handling, drainage, and part geometry.

Environmental severity and corrosion are considered in aircraft design, materials selection, and management processes as described in MIL-STD-1530D, MIL-STD-3063, and AC 43-4B. Although corrosion resistance may be secondary to the primary design constraints of weight and strength, corrosion performance can have a significant impact on aircraft integrity, availability, maintainability, and overall lifecycle costs. Operation and support costs of an aircraft may range from 50 to 70% of the total acquisition costs, according to Jones et al. (2014), and corrosion is estimated to be 24% of the total maintenance costs and 20% of non-availability for U.S. Department of Defense aviation as determined by the Logistics Management Institute (2018).

Although environment spectra and material interactions that cause corrosion protection system breakdown and atmospheric corrosion of aircraft can be complex, it is possible to measure environmental parameters and corrosion of surrogate corrosivity sensing elements to assess the risk of atmospheric corrosion. For more information, refer to ISO 9223, ISO 9225, ISO 9226, Agarwala et al. (2000), Brown et al. (2012), Demo and Friedersdorf (2015), Kouril et al. (2013), Ganther et al. (2017), Diler et al. (2017 and 2021), and Wilson and Muscat (2012). These measurements of environment spectra and corrosivity have demonstrated capabilities for short-term assessments of performance and risk associated with new coatings, material combinations, and corrosion control practices, and longer-term monitoring to assess the impact of operations, maintenance, and base location on individual aircraft.