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DETECTION AND ASSESSMENT OF AIRCRAFT CORROSION

Submitted by

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ABSTRACT

The detection and assessment of existing corrosion, or the onset thereof, in aircraft structures, related systems and components is of major concern to the United States aviation community. In this work several types of ion- and photon-beam analytical techniques were applied to the detection and assessment of corrosion. A method of laboratory classification of surface corrosion, and the identification of a corrosion preventative compound (CPC) applied on skin material removed from aircraft structures was developed. The results of this research will be useful in the development of instrumentation and inspection techniques to detect and assess corrosion. These techniques also will be useful in studying the mechanisms and efficacy of current and future CPCs. Developed instrumentation and inspection techniques have enormous potential for commercial and military application in many areas, including the transportation, nuclear, petroleum, and building sectors.

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1. Introduction

Corrosion detection, assessment, and control is a major problem for industry in the United States. In particular, corrosion seriously affects the continued airworthiness of the aging aircraft fleet. The development of inspection tools and instrumentation for non-destructive inspection (NDI) which are cost-effective, easy to operate, and provide accurate, dependable results therefore has major national importance. Of equal importance is the development of standard references with which to compare the inspection results, to provide a firm basis for making the required airworthiness decision.

When moisture and air interact with aluminum a chemical process occurs, which over a period of time will compromise the integrity of the aircraft structure. The corrosion process occurs when cells created through electrolytic action, like tiny batteries, support the transfer of electrons which weaken and destroy the aluminum structure. When an aircraft is based around coastal or industrial areas, the salt and pollutants in the moisture laden air act as catalysts and the electrolytic action is compounded and accelerated. Early detection and assessment of corrosion is the best way to assure airworthiness and prevent catastrophic failure such as the Aloha airlines accident.

Existing methods of corrosion control include structural and system design, material selection, inspection and maintenance programs, and modification of the environment through the use of protective coatings applied both externally and internally to aircraft structures. For general aviation (GA) purposes, protective coatings are broken down into two categories, paint and corrosion preventative compounds (CPCs).

The reduction and control of external corrosion is accomplished by the application of paint or a CPC. Before such application it is necessary to remove existing corrosion. As a result, such treatment is generally limited to readily accessible areas on the aircraft structure. In general, external structure is more readily accessible than the internal structure. Only a small fraction of GA aircraft internal surfaces are observable through inspection openings, so corrosion on both structural components and the skin progresses unnoticed until perforation or sudden failure occurs.

The most common method of preventing corrosion, or the onset thereof, is to coat the internal surfaces of the aircraft with various CPCs, meeting applicable Military Specifications (Mil-Spec), or Boeing Material Specifications (BMS). Numerous such

compounds exist. The FAA accepts and references these specifications, but they are not actually FAA approved. Without approval, inspection and maintenance personnel face a regulatory dilemma. If they apply these potentially beneficial compounds to aircraft, they are in violation of the Federal Aviation Regulations (FARs). To date there has been formal no resolution of the problem.

* Basic Aircraft Research (BAR) is developing the first *FAA-approved Process Specification for the above. Approval *requires *that CPC effectiveness be demonstrated, and its mode of *action be *known. Any limitations or possible risks must be *identified, and *recommended applications and use must be *specified.

The overall purpose of the present Cooperative Research and Development Agreement (CRADA) between BAR and Brookhaven National Laboratory (BNL) was to evaluate problems associated with aircraft corrosion detection and assessment, CPCs, and current GA inspection methods. The results of this research are intended to serve as the basis of a larger future effort directed towards supporting the GA community.

This project consisted of field-driven research designed to lead to direct, practical, cost-effective solutions, which could be transferred in a timely fashion to resolve corrosion problems encountered by GA inspection and maintenance personnel.

More specifically, this research began to develop the following field-related solutions:

- * 1. Development of a visual standard which would allow *inspectors and maintenance personnel to uniformly assess the *degree of GA aircraft corrosion throughout the industry,
- * 2. Development of a standard or new methods and techniques *for inspecting aircraft, and detecting and assessing corrosion,
- * 3. Exploration and determination of the mechanism by which a *CPC works, so that its use and application can be optimized or its *formula improved for specific application.

Robert E. Green, director of Johns Hopkins University's Center for NDT and one of the field's most eminent scientists states "A number of people are doing research on aging aircraft. As a first order, they don't need to to any research. Researchers should implement systems that are there. I'm not saying no research needs to be done. But I would like to see something done now, especially for older aircraft."

This CRADA, for the first time, utilized direct GA field experience to determine both the direction and application of research at a national laboratory with guidance and review by an FAA Aircraft Certification Office (ACO). Emphasis was placed on the cross training of field personnel, scientists, and engineers during this work. Also, of particular interest, is the deliberate direction away from established methods and techniques that this work took. A major focus was placed on the development of, the search for, and the adaptation to the field, of techniques or procedures already proven scientifically, but not yet applied to real-world corrosion problems.

2. Significant Accomplishments

* The majority of the CRADA research was based on the use of *2-MeV $^4\text{He}^+$ beams to examine the corrosion of aircraft aluminum *using Rutherford Backscattering (RBS). The RBS method measures *the elemental concentrations in the near-surface of the material *investigated. RBS has a multi-elemental sensitivity and limits *which range from minor to trace levels, depending on the atomic *number of the material. The relatively low energy of the beams *limits the depth of material probed so that our results hold for *the near-surface region of the materials studied. Since helium *ions have a range in aluminum of 7 micrometers, the maximum depth *probed was about 3.5 micrometers. A baseline standard was *established using clean aluminum samples obtained from the field, *which aided in the interpretation of the findings which were *affected by the presence of surface contaminants. Very *preliminary efforts were devoted to demonstrating the use of *photons produced by the decay of ^{109}Cd for *in-situ* detection and *assessment of aluminum corrosion.

Determination of a Corrosion Index

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The current method of determining or classifying the degree of corrosion on an aluminum aircraft surface is dependent upon qualitative visual evaluation by the holder of FAA Inspection Authorization (IA). A new method developed here gives a quantitative value for corrosion that can be used to calibrate and verify the accuracy of different IA's qualitative determination. *Specifically, a corrosion index was developed based on RBS *measurements of the relative amounts of oxygen and aluminum in the *specimen being investigated. The procedures used are briefly *described below.

* Sixteen skin samples of Alclad 2024-T3 were collected from
*aircraft based in Long Island, New York; Panama City, Florida;
*Albuquerque, New Mexico; and Hayward, California. The degree of
*corrosion of the samples were first assessed by an FAA licensed
*aircraft inspector (IA) based at the above locations. Samples
*were assessed as clean, light, moderate, or severe corrosion.
*Samples were then prepared by cutting them into 1.27 cm x 1.27 cm
*squares.

* The samples were then characterized by RBS using 2.0 MeV
*helium ions from the BNL Van de Graaff accelerator. The beam was
*collimated to a 1 mm size at the target, and the energy spectrum
*of the scattered helium particles was determined using a 30 mm²
*silicon surface barrier detector with an energy resolution of
*about 15 keV. The detector was placed 10 cm from the target at an
*angle of 150° to the incident beam.

* Typical spectra obtained are shown in Figures 1A-1D. The
*spectrum in Figure 1A was obtained from a clean aluminum surface,
*and was used to establish a baseline standard. A relatively sharp
*peak is observed for oxygen, indicating the presence of a thin
*surface oxide film known to form on aircraft aluminum. A typical
*lightly corroded specimen gives the spectrum shown in Figure 1B.
*Here, the oxygen layer has grown in thickness, but is still less
*than the range of the alpha particles in the aluminum. Spectra
*for typical moderately and severely corroded aluminum are given in
*Figures 1C and 1D. The thickness of the corroded region is now
*greater than the range of the helium particles, and the oxygen
*concentration is represented by a step in the energy spectrum of
*the scattered particles rather than a peak.

* The corrosion index is defined to be proportional to the ratio
*of the step sizes for oxygen and aluminum. The step for oxygen
*is measured so that the surface peak is not included. Values for
*the corrosion index for the specimens shown in Figures 1A-1D are
*given in the figures. The size of the ion beam is relatively
*small so that variations in the corrosion as a function of
*location on the specimen can also be accurately determined. Thus,
*allowance can be made for variations in the corrosion from point
*to point.

A record of invention was filed with the BNL Patent Office on
16 April 92, Re: BNL 92-12, R.L. Maldonado, et al, "Aircraft
Corrosion Analyzer (ACA)- Corrosion Index." A patent application
is currently under consideration.

Determination of CPC Signature

* There is currently no method of determining the effectiveness
*or the type of CPC applied to an aircraft to prevent or control
*corrosion. An RBS method has been developed which provides a CPC
*signature and can be utilized to provide qualitative assessment
*regarding its efficacy. RBS can be used to show whether a CPC has
*been applied to a surface, and also by measuring the
*concentrations of atoms, can be used to distinguish between
*different types of CPCs. The efficacy of different CPC's on
*aluminum can therefore be determined by comparison of spectra over
*a period of time.

* A collection of 23 known CPC's currently used in the
*aviation field was established as the basis for evaluation and
*comparison. In this case, carbon foil samples were mounted on
*target holders. The samples were treated with 11 of the CPCs,
*which met either Mil-Spec or BMS specifications, and allowed to
*dry. RBS analysis was performed on these using the method
*described above for determining the corrosion index. Typical
*spectra obtained are shown in Figures 2A and 2B. The results
*showed that there were differences, or individual signatures could
*be identified for the various CPCs.

A record of invention was filed with the BNL Patent Office on
16 April 92, Re: BNL 92-13, R.L. Maldonado, et a., "Aircraft
Corrosion Compound Analyzer (ACCA)- CPC / CDC Signature." A patent
application is currently under consideration.

3. Significant Problems

Would skin samples of other types of aluminum designations
found on various types of aircraft yield the same index results?
Would this method hold true for other types of metals, such as iron
and stainless steel? Will different indexes need to be developed
to accomodate other metals? Would this method hold true in a
relatively oxygen free environment such as that encountered in
space?

How would the CPC signatures change over a period of time? Do
weathered CPC's give the same signature as freshly applied CPC's?
If not, can a signature still be obtained which can be
differentiated from that of other CPC's? If more than one CPC has
been applied to the same surface over a period of time, can a
differentiation still be made? Would there be any way to determine
which CPC was applied first?

4. Industry Benefits Realized

Results of the present CRADA research will serve as the basis for providing GA aircraft inspectors with both quantitative and qualitative tools necessary to detect and assess corrosion. This *can take the form of commercial products or services. One such *service would be the analysis of coupons or inspection plates *regularly removed from GA aircraft, during 100 hour or annual *inspections, which would then be analyzed in the laboratory to *detect and assess the degree of existing corrosion or the onset *thereof. The results would provide the inspector with a standard *corrosion reference point for a particular aircraft, both *supporting the need for remedial action and any airworthiness *determination.

* A second service would be the analysis of surface composition *to determine whether the aircraft had previously been treated with *a CPC. The results would provide the inspector with the type of *CPC, as well as a means of determining its efficacy in the *operating environment over one or more inspection intervals.

* A third service, based on the preliminary results obtained *using Compton Scattering Spectrometry, would be the manufacture of *a hand-held field instrument for *in-situ* detection and assessment *of corrosion in inaccessible locations of the aircraft.

5. Laboratory Benefits Realized

A main benefit realized by this first BNL CRADA, is a demonstration to government and industry that basic research at BNL can be effectively applied to the practical resolution of current problems in the important area of aircraft corrosion. This is evidenced by the generation of specific potentially patentable results.

Ion- and photon-beam analytical methods developed under this CRADA can also be used as tools to study corrosion problems ranging far beyond the aircraft industry.

The use of RBS to assess the extent of corrosion and the results of surface treatment with CPC's will provide fruitful research areas for DOE programs. The results demonstrate the utility of basic research programs which are specifically focused on the development of new types, or the adaptation of current laboratory instrumentation to industrial problems.

6. Recommended Follow-On Work

A large scale comparison needs to be made between the corrosion index results and field results obtained visually. This would serve to introduce and validate the usefulness of the corrosion index to inspection and maintenance personnel in the field.

The CPC's which were not tested need to be tested. A database needs to be developed as a basis for comparison and as a readily available reference for field personnel. Changes which occur as a result of weathering of CPC's need to be investigated.

It would be extremely useful to continue work along the initial lines, and particularly, to move on to apply them in much greater detail in to the study of the classification and assessment of other forms of corrosion, as well as the behavior of the CPCs on different types of corrosion, in different types of environments.

7. Potential Benefits From Pursuing Follow-On Work

Any progress made in developing improved methods to detect, assess, and protect against the effects of corrosion will have substantial impact on the United States economy. While the research began as a study related to aircraft corrosion, and while that segment of the industry is a multibillion dollar effort, it is important to stress that the results have larger implications and could be used to good effect in many other sectors of the economy. For example, these methods could be applied to common problems in electrical power generation, in both conventional and nuclear power plants and in the national infrastructure, such as bridges. Thus the relatively small investments needed to further pursue the present research, could have substantial results.

Figure 1. Typical RBS spectra of aircraft aluminum specimens (Type 2024-T3) alloy. Results are for specimens with (A) no corrosion, (B) light corrosion, (C) moderate corrosion, and (D) severe corrosion. The chlorine observed is attributed to the chemical causing the pollution.

Figure 2. Typical RBS spectra of corrosion preventative compound (CPC) signature on carbon foil. Results are for specimens (A) CPC1.091 and (B) CPC3.091.