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Improved Corrosion Maintenance Practices

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The USAF, and much of the aerospace industry, currently manage corrosion by providing clear engineering direction that it will be found and fixed prior to becoming a structural or safety concern. New procurements have been reduced and current fleets are now at, or projected to be beyond, their original design lives. While there is significant fatigue life left, corrosion maintenance costs are escalating rapidly. Initial protection systems have broken down and corrosion is becoming the dominant factor in the life of the aircraft.

Under the current engineering policy, often much of the corrosion cost is associated with the dismantling and reassembly of aircraft structure and not the repair itself. Where the corrosion is superficial many of these repairs could be done at a more opportunistic time were there the tools to assure there would be no compromises to the structural integrity. Likewise, there are currently no tools with which to quantify the structural impact of benefits from corrosion abatement technologies. The "find and fix" approach supports better prevention, detection, and repair technology development. However, it does not quantify the beneficial impacts nor facilitate the needed changes in maintenance practices to significantly reduce the rapidly growing corrosion repair costs.

Current engineering philosophy requires fleet management vs. management by individual tail number. There are no tools to quantify the structural significance of a given level of corrosion nor determine alternative required inspections. Likewise, there is no tool to define exactly how good NDI for corrosion must be, nor are the needed parameters (pitting, thickness loss, etc.) specified. NDI techniques that identify nuisance corrosion can be counterproductive driving up both costs and extending schedules.

The lack of tools to analyze the mechanical impacts of corrosion on aircraft structure also result in less robust maintenance practices because the impacts of improvements can only be measured subjectively. Benefits from specific maintenance changes cannot be quantified. Forging replacements are machined from thick plate or bar stock of the same alloy but with very different grain structure. The relative lives and corrosion characteristics of the different material forms are not determined or tracked. Corrosion Prevention Compound (CPC) use is authorized but not mandated nor are CPC programs focused and tailored to the overall maintenance program since the mechanical impacts cannot be quantified. Likewise, there are no tools to objectively guide in the choice of repair options, which are now chosen based on the judgment of an individual engineer.

To facilitate improved corrosion maintenance practices the necessary tools are being developed in a multifaceted and comprehensive corrosion program. Many aspects of this program will be covered in other papers being presented here. However, an integral part

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of such an effort is the definition of the severity of the environment to which the aircraft is exposed. For many years, attempts have been made to measure the corrosion severity of the natural environment in order to anticipate the levels of corrosion damage that may be expected or to define a reasonable level of corrosion protection to be required.

In the 1970's, the USAF developed an algorithm using readily available weather parameters for predicting corrosion damage under the Pacer Lime Program. The parameters included chloride deposition levels based on distance from the sea, average annual rainfall, average annual humidity, SO2 levels, total suspended particulates, UV and 03 levels. This algorithm proved useful as a tool for determining aircraft wash and rinse frequencies and gave a rough approximation of the severity of the environment (Reference 1). However, this did not provide a close correlation with actual corrosion maintenance costs or hours nor did it provide insight into the type of corrosion damage to be expected in specific structure on a specific aircraft. A much larger study was done in the 1980's under the National Acid Precipitation Assessment Program. Incorporation of this information into an improved algorithm gave some improvement but still there were many instances where the ranking did not track with the corrosion being encountered. Factors were then incorporated for extraneous sources of chlorides, for instance road salts in the winter, and roughness of the seas, prevailing winds, etc. (Reference 2). Still the results were not satisfactory for use with any predictive modeling efforts. Subsequent analysis indicated that the revised algorithm might be adequate if there were sufficiently detailed data to allow integration of the parameters over time. However, such detailed data simply does not exist for all of the locations of concern to the USAF. Comparison of the calculated severity to that measured showed reasonably good correlation in the milder environments but a significant under estimate in the more severe environments (Reference 3).

The alternative of conventional exposure testing at all locations seemed impossible given the costs and time required. However, conventional exposure racks were placed at 6 severely corrosive environments where KC-135 aircraft were stationed. Various panels and lap joint configurations were exposed for 1 to 5 years giving some indications of the expected type and extent of corrosion damage in these joints. These racks also allow correlations to be made with corrosion maintenance experience on the aircraft stationed at these locations.

A unique corrosion exposure system, developed and refined by Dr. William Abbott, was also employed (Reference 4). This exposure system, which is quite simple, provided amazingly accurate results fairly quickly. The modular rack measuring approximately 6" x 6" x14" can be mounted on any supporting structure including fences, poles, etc. (Figure 1).
In this rack there are 4 cards, each containing 5 strips of bare metal including silver, copper, 2 aluminum alloys, and mild steel (Figure 2).

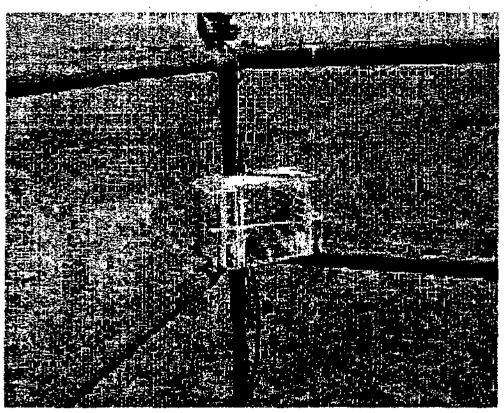

Figure 1. Example Of Typical Sample Installations In Proximity To Runways Or Aircraft Ramps

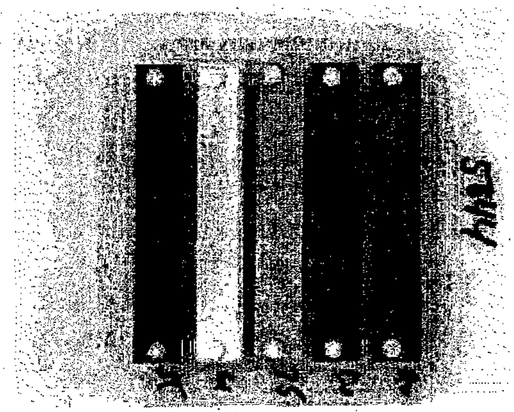

Figure 2. Typical Corrosion Test Card Containing 5 Metallic Coupons; 4 Cards Per Test Site

One card is removed every 3 months and various analyses are done to ascertain the relative corrosivity. The analysis of the silver coupon yields intelligence as to the chloride element of the corrosion process with additional indications of the affects of sulfur containing components when analyzed in conjunction with the copper coupon. These metals allow some detailed insight into the severity of a specific environment to specific types of metals. Likewise, precise measurement of weight losses and gains of the aluminum and steel coupons allows determination of the severity of the specific environment for those materials (Reference 4). Exposure testing has been done at over 80 USAF sites, from Antarctica to Saudi Arabia, and from seacoast to desert. These exposures were done on uncoated and openly exposed coupons. Significant new information was obtained.

This testing yielded several surprises. Chloride species are found at virtually all locations, with close proximity to the seacoast not a prerequisite (Figure 3). This result may be due to entrainment of oxidized sea salt aerosols in upper atmosphere wind currents. There is very limited evidence of corrosion resulting from sulfur containing compounds though this cannot be eliminated as a possibility. With the cleanup of the environment, SO2 levels, and the associated acid rain, have been reduced by orders of magnitude in many areas but corrosion levels have not changed proportionally.

Other information extracted from this testing indicates that there is minimal seasonal variation in the corrosion rates and that rates calculated after 3 months are reasonable accurate and correlate closely with those obtained after a full year of exposure (Figure 4). Likewise, relative values of chlorides obtained from the silver coupon alone provide a reasonably good indication of the severity of that environment for most locations though there are exceptions. Use of the silver sensors alone for shorter periods thus allows a much faster and inexpensive means of screening new and/or temporary locations though the information is not necessarily sufficient for robust predictions.

The relative severity of most environments to the various metals is roughly the same although there are some exceptions and minor shifts in relative rankings. On boldly exposed coupons the rates for some aluminum alloys varied almost 300:1 over the range of locations (Figure 5). Absolute rates of corrosion of 2024, 7075, and 6061 aluminum alloys spread fairly cons istently over nearly a 10:1 range with the corrosion rate increasing with the amount of alloyed copper, as expected (Figure 6). Across the locations, the rates for mild steel covered a nearly 200:1 range (Figure 7).

These ranges may become significant when analyzing specific types of structure or components. For instance, an environment specifically severe for copper could yield a disproportionate number of avionics failures. There is some indication from maintenance data that this might be the case. This experience is more clearly shown in locations specifically damaging to steel. Here support equipment and vehicles exhibit much more damage proportionally than do aircraft with primarily aluminum structure.

Some of the unexpected results include those for the Saudi Arabian desert, which has a very low humidity but a fairly high corrosion rate. This might be explained by the fact that the chloride content of the sand is approximately many times that found, for instance, on an US mainland beach. Kunsan AB Korea, located on the Yellow Sea, showed significantly higher corrosion rates than would have been projected based on the chloride levels alone. This may be the result of higher humidity levels and or other pollutants. Guam and Hawaiian locations had much lower rates than would have been projected based on the chlorides (Figure 3). Clearly other factors or synergistic effects exist.

This information is useful but insufficient to provide a basis for rates for corrosion predictive modeling. First, it cannot be concluded that corrosion rates occurring within a lap joint, for instance, will be the same as those on a boldly exposed surface. Likewise, just because an aircraft is based at a specific ground based location, does not mean that the severity of that location is the primary driver of the corrosion rates. This is particularly true of large transport aircraft, which routinely are exposed to a variety of environments.

Aging Aircraft Corrosion efforts have most recently focused on anticipating and managing lap joint corrosion. Thus, meaningful environmental severity data was required. In addition to the simulated and actual lap joint samples exposed on the racks at the KC-135 bases, small lap joint coupons were exposed on these racks at multiple locations. Not only are corrosion rates required for this effort but also the damage profiles to allow the mechanical impacts of the corrosion damage to be determined. This profiling has been done using both laser profilometry and other methods. Characterization of this damage and its impact is the subject of several other papers being presented at this conference.

The lap joint exposures have resulted in further refinement of the initial rankings. The corrosion rates of aluminum lap joints are at least 5 times larger than those of the openly exposed samples with values as high as 20 times larger. However, the 300:1 spread in openly exposed rates over the various locations shrinks to less than 20:1 for the laps. Furthermore, the damage profiles are vastly different than that of the openly exposed coupons with most of the damage occurring just inside the occluded area of the lap. From this and other laboratory testing, corrosion rates appear to be high even in areas judged to have lower chlorides and otherwise appearing to be less severe. Ostensibly it would seem a threshold of chloride is required to nucleate and sustain corrosion after which times of wetness etc. may be the determining factors for rate. While the reasons for the observed behavior are open to speculation, this corrosion damage is being characterized and quantified for a broad range of environmental severities.

Associated laboratory studies have also shown that contaminants can easily be wicked into unprotected lap joints but a drying out of these joints does not occur except under relative extreme conditions. Thus, lap joints previously exposed in a severe environment are being moved to various more benign environments and the corrosion rates subsequently determined for both the previous exposed and newly exposed joints in the more benign environments.

To ascertain the validity of these indices for use in determining actual damage requires that these exposure racks be flown on actual aircraft so that severities could be established and matched to actual corrosion damage. Both interior and exterior locations of the aircraft must be measured for the data to be specifically beneficial. These and other types of exposure racks are currently being flown and data extracted. The racks are placed in interior cargo areas as well as wheel well areas of both USAF and US Coast Guard aircraft.

Such Environmental Severity Indices do not necessarily have to determine the actual rates used in the modeling, but rather may tie a particular exposure to a separately determined rate derived from other work. As with fracture mechanics models, this work is focused on rates at which existing corrosion in specific materials and specific structure will grow. This then may serve as a basis for maintenance and inspection frequencies. It may also provide a quantitative basis for opportunistic repair of corrosion rather than the currently mandated immediate action. The effects of exposure and mechanical stress on the breakdown of protective systems is not a critical aspect of this effort which focuses primarily on the growth rates of preexisting corrosion. Complimentary work is being done in other research and development programs to ascertain the time to nucleation of such corrosion.

While extensive exposure testing continues, both the quality and quantity of data should allow anticipatory approaches to corrosion inspection and repairs. These indices will soon be included in USAF technical data as the basis for some prevention activities. As the tools are developed, improved corrosion detection, analysis, and repair options can be optimized and focused. This should facilitate management of corrosion by specific tail number, with opportunistic corrosion inspection and repair.

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FIGURES

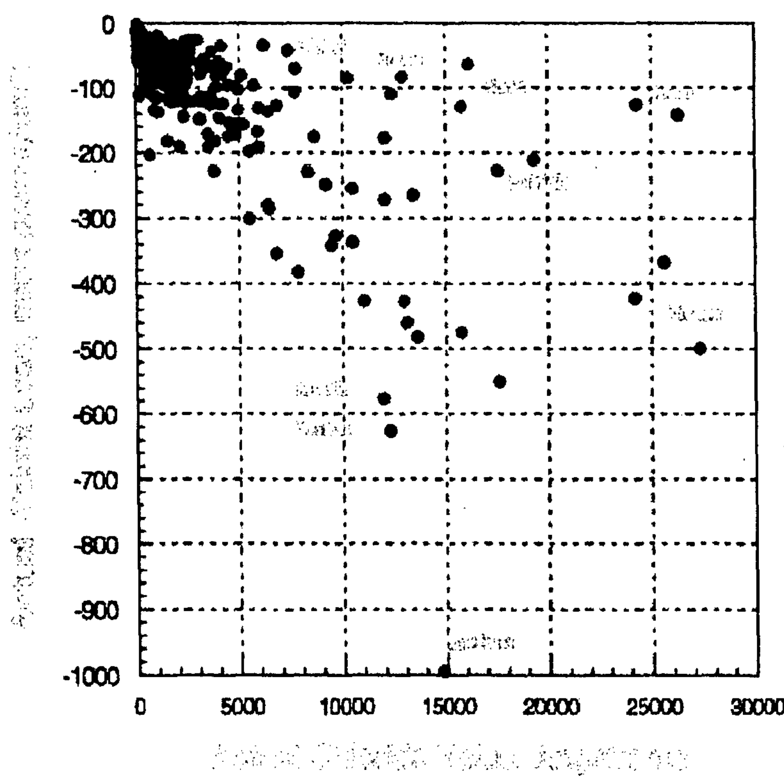

FIGURE 3. CORRELATION OF 6061 ALUMINUM WITH CHLORIDE SENSOR VALUES

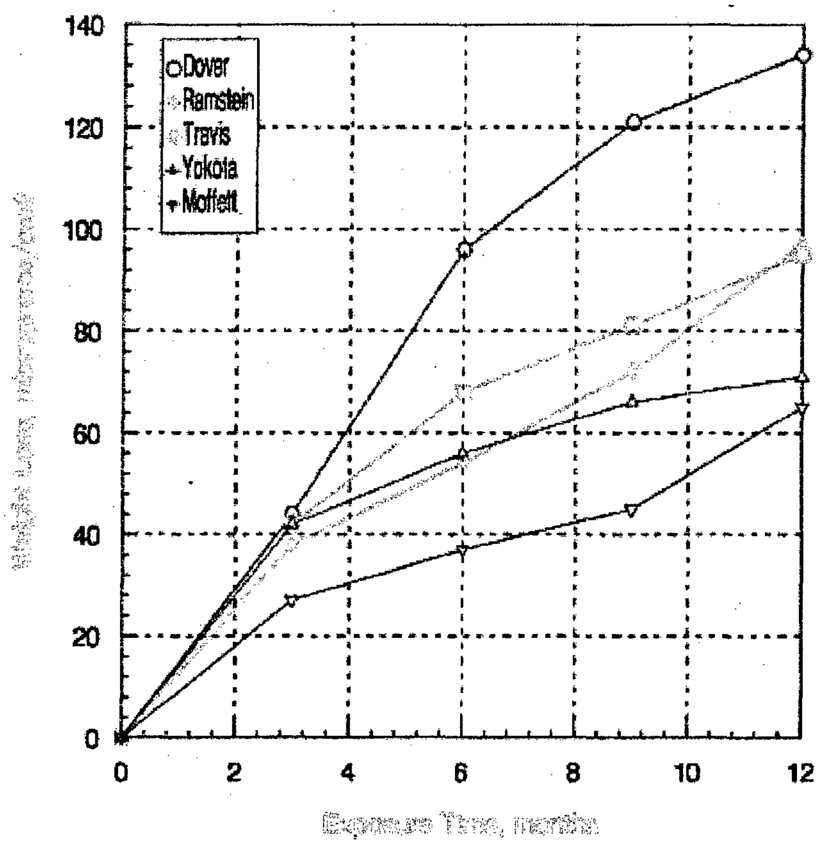

FIGURE 4. CORROSION OF 6061 ALUMINUM
DURING OUTDOOR EXPOSURES

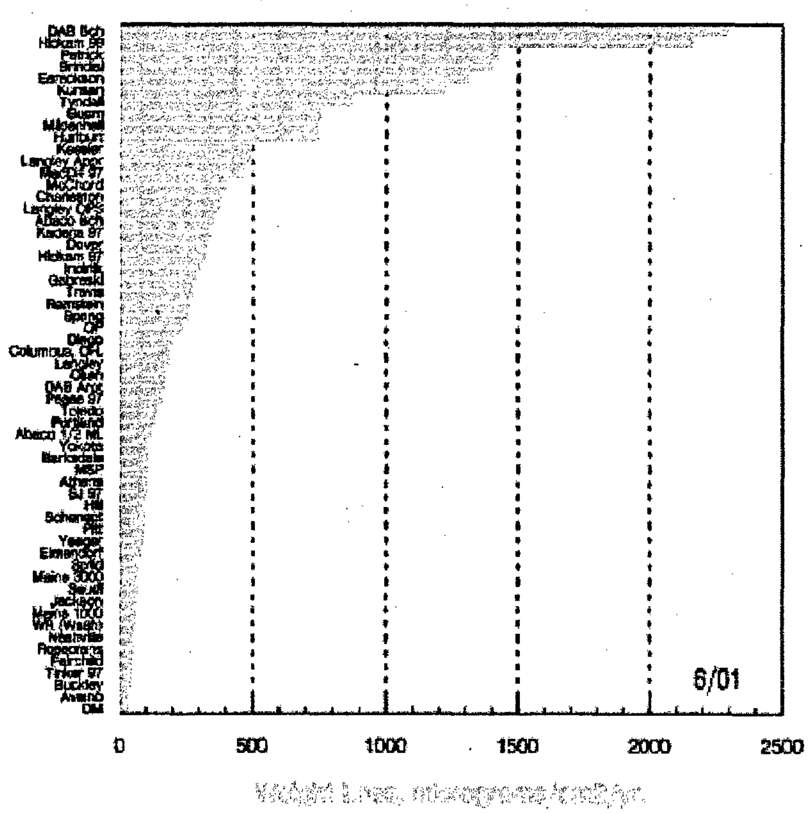

FIGURE 5. WEIGHT LOSS OF 7075 ALUMINUM
AT OUTDOOR FIELD SITES

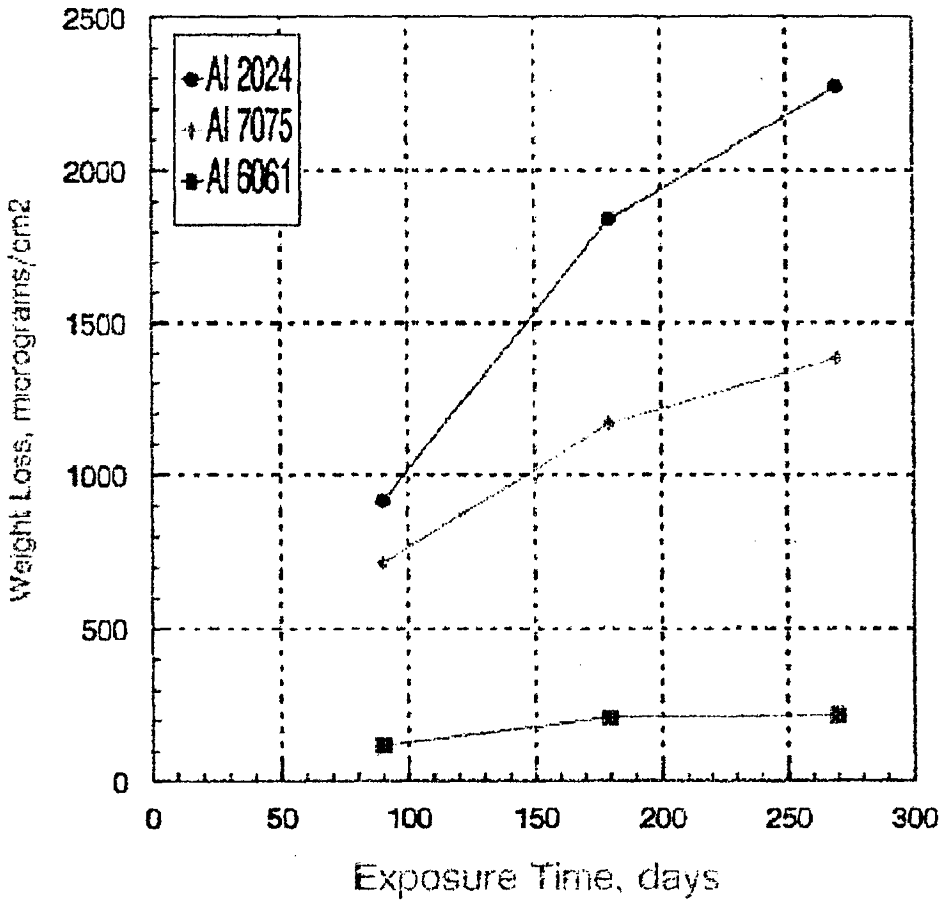

FIGURE 6. EFFECTS OF ALLOY TYPE ON CORROSION OF ALUMINUM

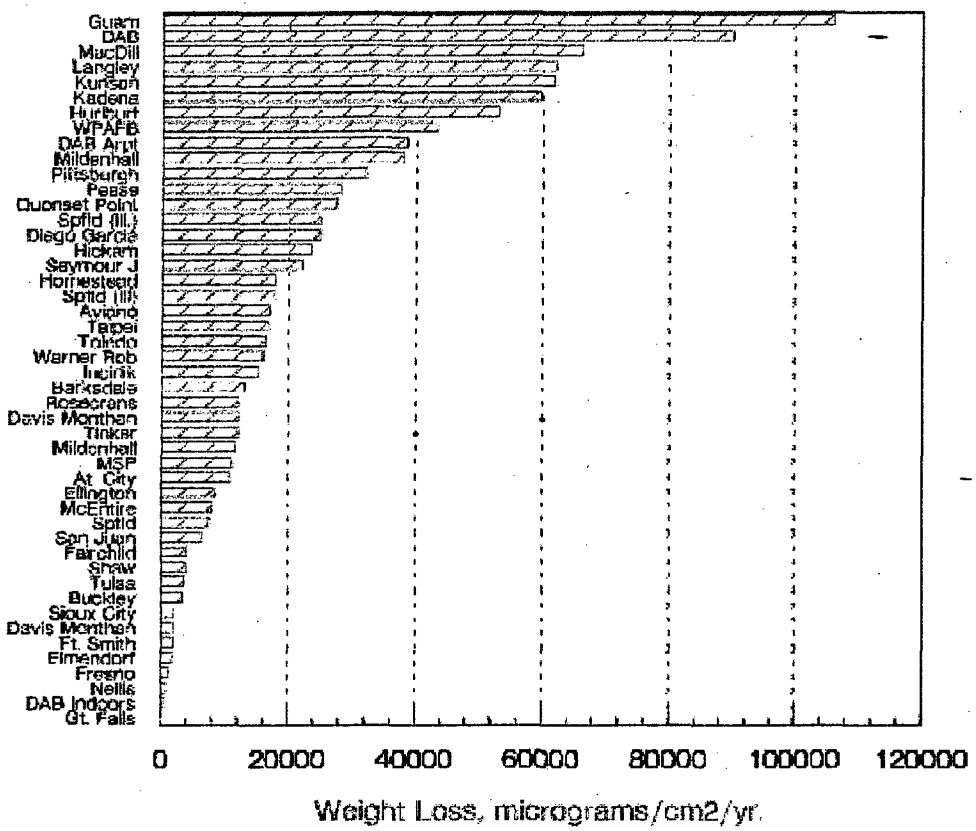

FIGURE 7. WEIGHT LOSS OF 1010 STEEL IN OUTDOOR BASE ENVIRONMENTS