EXECUTIVE SUMMARY

An Experimental Study of the Effects of Wash-Rinse Intervals on Corrosion

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Over 30 years ago the USAF conducted extensive ground based and laboratory corrosion testing under the Pacer Lime program. This effort resulted in algorithms which predicted the expected corrosion damage at a specific location using 7 environmental parameters. Over the years there were locations where those predictions did not seem to match the experience although this proved adequate for the majority of the locations. Based on the Pacer Lime results and engineering judgment, wash cycles were set as 30 days in severely corrosive environments, 90 days in moderate environments, and 120 days for mild environments. In some cases specific managers elected to shorten these cycles for a system or location as they felt was warranted.

In the late 1990's, Battelle developed a unique corrosion exposure rack which could easily be deployed to any USAF location and provided real exposure data on multiple materials. This has been the subject of previous briefings in this and other conferences in the past 5 years. In addition to corrosion rates on various materials, a coupon of silver allows "reactive" chlorides to be determined by the measurement of the thickness of the AgCl film. Since NaCl is considered the primary corrodent in most cases, knowing this parameter was deemed important for this work and has indeed proven to be true.

In conjunction with the wash program, which was not as stringent as the USN program of a 7 day wash frequency in severe environments, the USAF also instituted a program requiring freshwater rinsing of aircraft after every flight or at the end of every day if they have flown under 3000' over saltwater.

It is often presumed that NaCl is the primary driver of atmospheric corrosion in the presence of moisture. This is consistent with the observation that corrosion is generally far worse in locations adjacent to or near salt water. However, for many years, analysis of corrosion products from many sources has failed to identify stoichiometric amounts of sodium. Most recently, analysis of corrosion products from lap joints of numerous aircraft from may different environments by electrocapillary phoresis again failed to find the expected levels of sodium based on the amount of chloride.

While washing has been noted to reduce corrosion, the outdoor exposure of some aircraft parts being washed to determine the affects of washing on paint condition, did not always reflect a reduction in corrosion rates on bare coupons. Further testing indicated there was little benefit to washing bare coupons unless the washing was sufficiently frequent.

The easily deployable Battelle outdoor exposure racks allowed corrosion rates to be measured and damage characterized for most of the USAF aircraft basing locations for multiple materials. Likewise the chlorides were determined as previously discussed. This information allowed comparisons to be made between corrosion rates and the observed levels of chlorides. It also allowed relationships to be established between measured corrosion rates and sensor readings thus allowing sensors to be used as verification of expected rates.

These observed chloride levels were measured by the thickness of AgCl films formed on a silver coupon. However, the reaction of NaCl on pure silver would not result in the formation of AgCl. Thus, there must be some chemical species other than NaCl acting on the silver. Likewise, the earlier Pacer Lime work did not indicate appreciable levels of chlorides at inland locations though some of those locations had a higher than expected corrosion severities. It should also be noted that if silver coupons are exposed per ASTM B117, in laboratory salt fog cabinets, no AgCl forms.

An atmospheric chemist, B. J. Finlayson-Pitts at Univ. of CA, has done extensive work over the past 10+ years which shows that small amounts of chlorine occur from UV acting on aerosol chlorides in the environment. Limited work done by Battelle, W. Abbott, has shown that this amount of chlorine at 70+% humidity will greatly increase corrosion rates. Thus, there is a basis for hypothesizing an alternate corrosion mechanism which might explain the observed behavior. Such an alternate mechanism would also have implications for corrosion prevention and control practices on fielded assets.

There is little doubt that aircraft corrosion results from multiple sources including the atmosphere and exposures from the aircraft itself. The atmospheric components no doubt include some species of chlorine, abundant from the seas, and humidity in addition to other lesser aggressive materials. Aircraft contaminants include such things as oils and greases, containing dirt and various other corrodents, carbon deposits, and spillage of such corrosive solutions as lavatory fluids, etc.

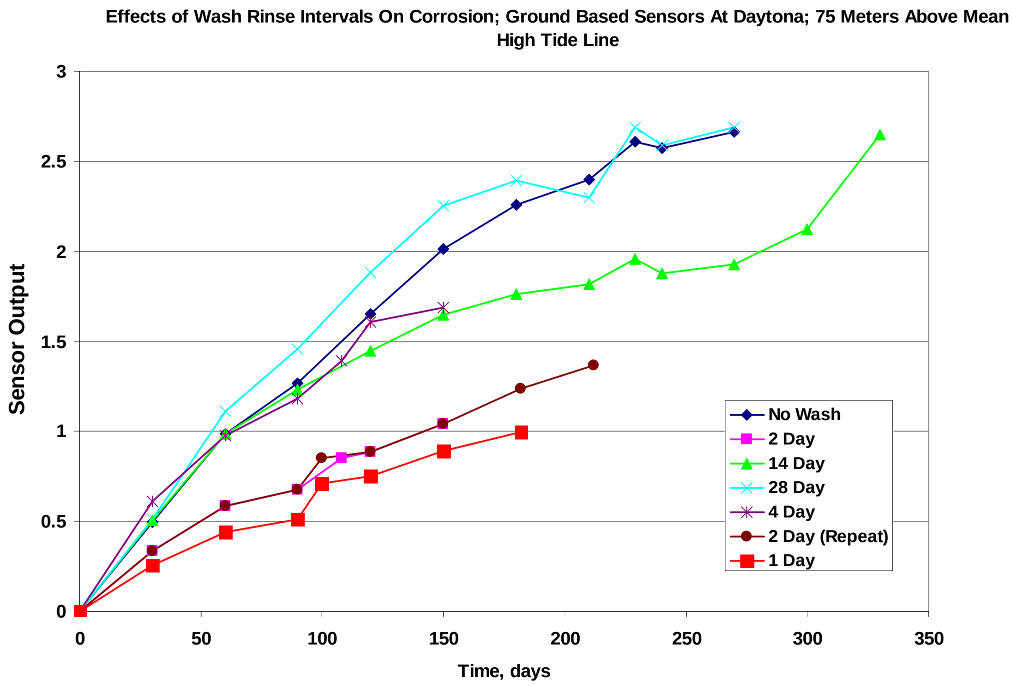
However, if gaseous chlorine naturally occurs in the environment in sufficient quantities to significant accelerate corrosion in humid environments, this could result in corrosion mechanisms accounting for the lack of sodium in corrosion products previously assumed to be formed via attack of NaCl. This theory would also better explain why corrosion rates drop off so drastically as the distance from the sea increases since the chlorine formation requires the chlorides to be in the aerosol form. The affects of distance from the sea on corrosion rates is currently being reinvestigated via an OSD funded project managed by Ms. Susan Drodtz and Mr. Vince Hock, at CERL. Regardless, if there is a gaseous step involved in the corrosion process, this part of the process would be reinitiated almost instantly following wash. It would also explain some of the intrusive nature of corrosion in internal areas of the aircraft not openly exposed. However, there is also data, previously presented at other forums, that shows that there is a drastic affect of sheltering on corrosion rates. This sheltering affect clearly translates to internal vs. external areas of the aircraft even though there is migration to the internal areas.

It is long been observed that accelerated corrosion testing in the laboratory do not directly relate to years of expected service in the real environment. There have been many unsuccessful attempts to reconcile laboratory corrosion data to real experience. If the laboratory testing was developed based on wrong assumptions as to the corrosion mechanism, then this could explain this difficulty. We believe some investigation of this theory would be warranted.

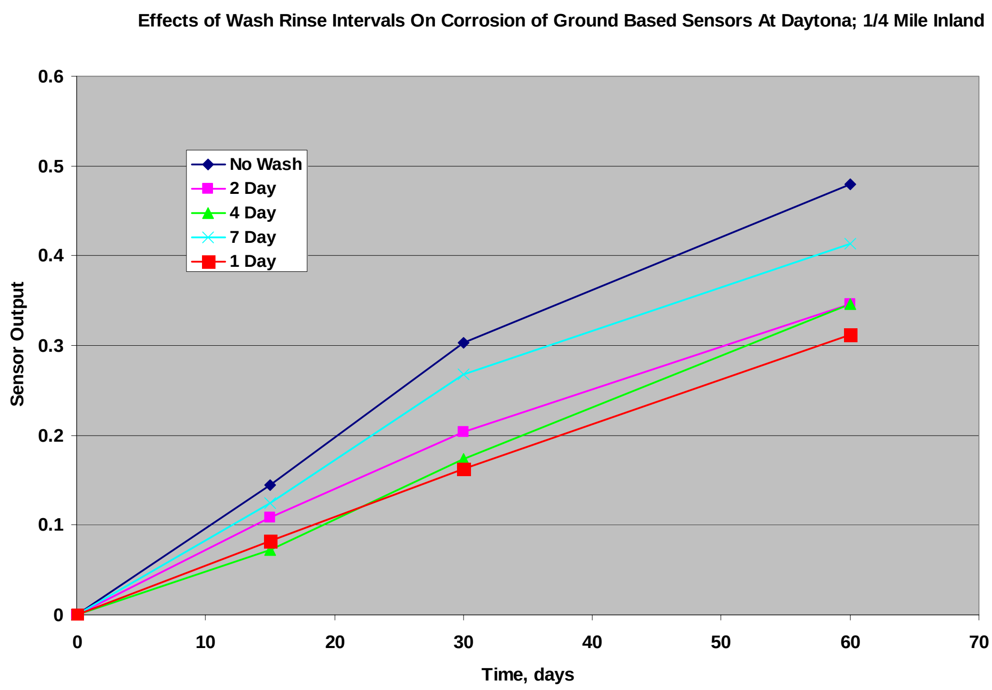
According to the hypothesis, we would expect the atmospheric corrodents to be more water soluble and easily removed via washing or rinsing than many of the contaminants from the aircraft itself. Since washing and rinse programs must address all sources of corrosion, which are many, these observations to date would have little to do with how an optimum wash and rinse program should be set up for the actual aircraft. However, to test this theory a study was begun using static ground-based coupons.

The initial phase of this study was exposure of coupons and sensors in environments of varying measured severities. These samples were and are being washed and/or rinsed at varying frequencies from every other day up to 28 days with the control not washed. Because there are numerous other test programs concurrently being done in these same locations using similar sensors and coupons there is also a much broader body of data with which to compare these results. The relative impacts of washing as compared to CPC usage prior to or after corrosion begins can be seen etc. Some of these static test results are available and will be shown in following slides with preliminary conclusions.

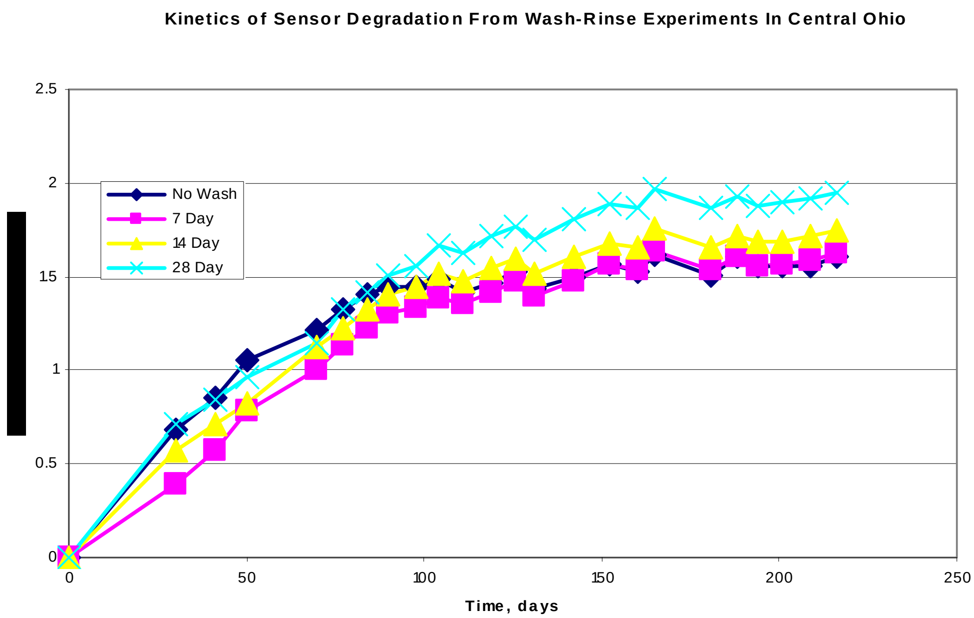
At the same time these static wash/rinse tests were conducted, multiple aircraft have had the same cumulative environmental exposure sensors installed as a part of a different program. These flight tests in multiple environments on multiple aircraft types have already provided a significant baseline using the existing wash cycles. Thus, flight testing of alternative wash and rinse cycles can quickly yield the necessary data for alteration or optimization of the USAF wash program to be explained in the following Figures.



This kinetic data shows the affects of various wash cycles right on the beach. The most important observation here is that if the sensors are washed every other day there is a significant reduction in the corrosion rate but if this cycle is extended to every 4 days there is little benefit. If the cycle is extended to 28 days there is virtually no benefit over not washing at all. It is critical to note that you cannot conclude then that there would be no reason to wash aircraft if you were using the USAF 30 day cycle since this data is only looking at atmospheric driven corrosion rates and does not include corrosive contaminants and dirt from the aircraft itself.



It has been observed that even 50 meters difference in distance from the salt water at very close distances from the sea can make a significant difference in the corrosion rate. The KSC beach exposure site has some difference in rate from the Battelle Daytona Beach test site even though they are very similar exposures in close geographical proximity. Thus, this exposure is less severe though only 0.25 miles inland from the sea. Please note that the time period and scales differ from the previous chart since this experiment was started much later. To date this data would show 2 things. First it shows a somewhat reduced corrosion rate using the same wash cycles as would be expected. However, it also is beginning to indicate the marked reduction in corrosion rate occurs somewhere between 2 and 7 days, with an indication that as the severity decreases the marked drop in corrosion rate occurs at a slightly increased wash interval.



The most significant information probably gleaned from the central Ohio data to date is that drastically reduced wash cycles will yield little benefit in the more benign environments. Time does not allow discussion of the kinetics but responses in this environment over time tend to be somewhat different than those nearer the seacoast.

The limited data to date on rinsing of the sensors at Daytona Beach shows little benefit from rinsing even every other day in this very severe environment. This likely means that even this frequency is not enough to reach the threshold level below which the contaminants are adequately removed. Since washing at this frequency does result in a significant reduction in corrosion rates, there is the possibility that inhibitors in the aircraft cleaners provide some residual affect or that rinsing alone is inadequate to remove sufficient amounts of the corrosive species. Currently testing has been revised to provide some mechanical agitation (gentle brushing) with the freshwater rinse to isolate the reasons for differences between washing and rinsing.

Preliminary results are as indicated. Since this testing is still in progress, it must be stressed that the results are preliminary and subject to revision as the data becomes more complete. However, at least in the milder corrosive environments, information is complete and consistent enough to indicate that savings can be gained with little or no impact on corrosion if wash cycles are relaxed.

Data to date does not refute the hypothesis as to potential corrosion mechanisms being different from those traditionally assumed. However, some of this data, at face value, does not necessarily support some of these theories. Further outdoor exposure experiments are in progress to resolve some of these inconsistencies and ambiguities. However, there are significant areas that beg for more basic research far outside the scope of this practically focused effort to optimize corrosion prevention and control practices in the operating environment.

Should flight testing confirm these conclusions for milder environments, then matching the wash cycles to the 180 day corrosion inspection cycle would eliminate many of the scheduling complexities while still assuring corrosion is controlled. Such a change would no doubt still require more frequent spot cleaning in aircraft locations subject to contamination from sources other than the environment, with more frequent washing also necessary in some geographic locations to maintain appearance standards. Since many of the USAF basing locations are in milder environments the potential for savings is large.

Currently OSD has approved FY 06 funds for flight testing of wash/rinse cycles. This flight testing is planned to be conducted on C-130's in a mild environment using the 120 day cycle as the control with test aircraft extended per previous discussion. Multiple sensors will be installed on each aircraft with monitoring to measure cumulative environmental exposure and identify locations on the aircraft where exposure results from aircraft induced conditions vs. the atmospheric conditions. H-60 Helicopters in a severe environment rinsed on greatly increased frequencies (daily) under field conditions will be monitored vs. a baseline of both C-130 and H-60 aircraft in a severe environment washed and rinsed per existing USAF TO requirements. These results will should provide "stand alone" data and will also be compared to a much broader body of sensor data from other projects in the same and different environments. Static outdoor exposure testing under Phase I will continue.

The wash/rinse study project should result in increased data in support of these programs in all services. However, this program also points to significant needs for research and development in this area. It should also be noted that while these are stand alone efforts they also must be seen in terms of a larger, and essential, strategy to move the management of corrosion from "find and fix" to "predict and manage". "Find and fix" is functional in many cases but with aging weapons systems this approach is simply not longer affordable.