AVT-373 Research Specialists' Meeting on Emerging Technologies for Proactive Corrosion Maintenance

Båstad, Sweden
9 - 11 October 2023

Technical Evaluator Report

Rick Mendoza
CEO and Chief Engineer ESTA Corp.
rick.mendoza@estacorp.com

1. BACKGROUND

Corrosion management is an essential part of life-cycle management for military platforms of most NATO nations, especially aging platforms. It has significant impact on the military platforms on both economic, safety and availability aspects. On the economic aspect, corrosion causes major cost that can affect a defense budget; recent studies estimate the direct cost of corrosion in the United States to be nearly $300 billion dollars per year (www.corrdefense.org). On the safety aspect, corrosion damage (e.g. pitting, stress corrosion cracking, etc.) and improper repairs can affect platform safety, such as aircraft structural integrity (AVT-140 report), and jeopardize military fleet mission success and availability.

In the age of rapid technology advancement, especially on science-based modelling, diagnostic and prognostic tools, there is a great potential for establishing a smart corrosion management approach to reduce corrosion costs, while maintaining safety and improving operational availability of military platforms. Many NATO nations are developing their own corrosion management policies and maintenance procedures.

In all NATO nations, there are increasingly demanding requirements to reduce the environmental footprint of military platforms, which affect and will have more effects on existing corrosion management policies. Considering the common interests and common/similar platforms operated by all NATO nations, it is deemed very useful to share the best practices on how to manage corrosion, and to discuss possible approaches to improve NATO nations' corrosion management.

This RSM directly supports the AVT mission on "Improve performance, affordability, and safety of vehicle, platform, propulsion and power systems operating in all environments for new and ageing systems through advancement of appropriate technologies".

2. OBJECTIVES OF THE WORKSHOP

- To share the latest insights in the corrosion risks associated with new materials used in platforms, chromate-free paint schemes and environmental exposures.
- To share the best practices on how corrosion is managed across the NATO nations, including diagnostic and prognostic tools, non-destructive inspection (NDI) techniques used to assess corrosion damage, and corrosion repair technologies.
- To discuss the possible approaches that will allow NATO nations to improve corrosion management.

- To discuss the latest insights in accelerated testing in relation to in-service measurements of the environment and corrosion.

These subtopics were further refined into more specific topics that more discreetly addressed these topics in the areas of:

- Chrome-free paint
- Corrosion testing
- Corrosion sensors and severity
- Corrosion sensor usage
- Contamination measurements

Corrosion detection and repair

3. ORGANIZATION OF THE TECHNICAL EVALUATION REPORT

The workshop was subdivided into three session each beginning on 9 October and ending on 11 October 2023.

The sessions consisted of providing live presentations followed by question and answer session, and a final Technical Evaluation debrief and roundtable discussion.

The list of Papers below is not listed in either chronological order of presentation nor numerically, rather they are subdivided based on type of topic.

There were six basic topics which we listed as follows:

1. Chromate Free Adoption Quest
2. Testing for Protective Finish Qualities
3. Sensors for Predictive Corrosion
4. Non-Destructive Inspection/Testing
5. Corrosion Repair Methods
6. Important Fields of Corrosion Work
7. Conclusions and Recommendations

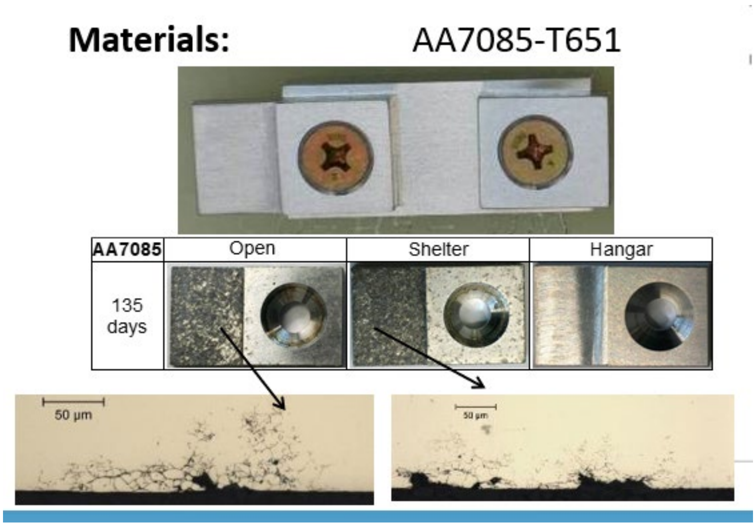
4.0 TECHNICAL EVALUATION

CHROMATE FREE ADOPTION QUEST

4.0.1 PAPER KN: THE AUSTRALIAN JOURNEY-TOWARDS CHROMATE FREE AIRCRAFT

Grant McAdam, Discipline Leader Atmospheric Corrosion Defence Science and Technology Group (DSTG), Australia

This Paper provides a description of the history of the international requirements to replace chromated pre-treatments and finish systems and the work that the Australian government has undergone to meet those requirements, as well as future work planned and a focused intent on evaluating and determining the influence of the operational location of Australian aircraft fleet on their overall corrosion effect. One revealing and interesting finding is that sheltered locations, where there is a cover over aircraft in an area open to the environment results in higher corrosion severity.



Much of the work presented centers on the evaluation of the Deft Non-Chromated Primer over Chromated Conversion Cr6 Pre-Treatment surface. The final results show that the primer provides adequate protection, however the leaching effect of Chromated Primers continues to provide superior performance as compared to the non-chromated primer.

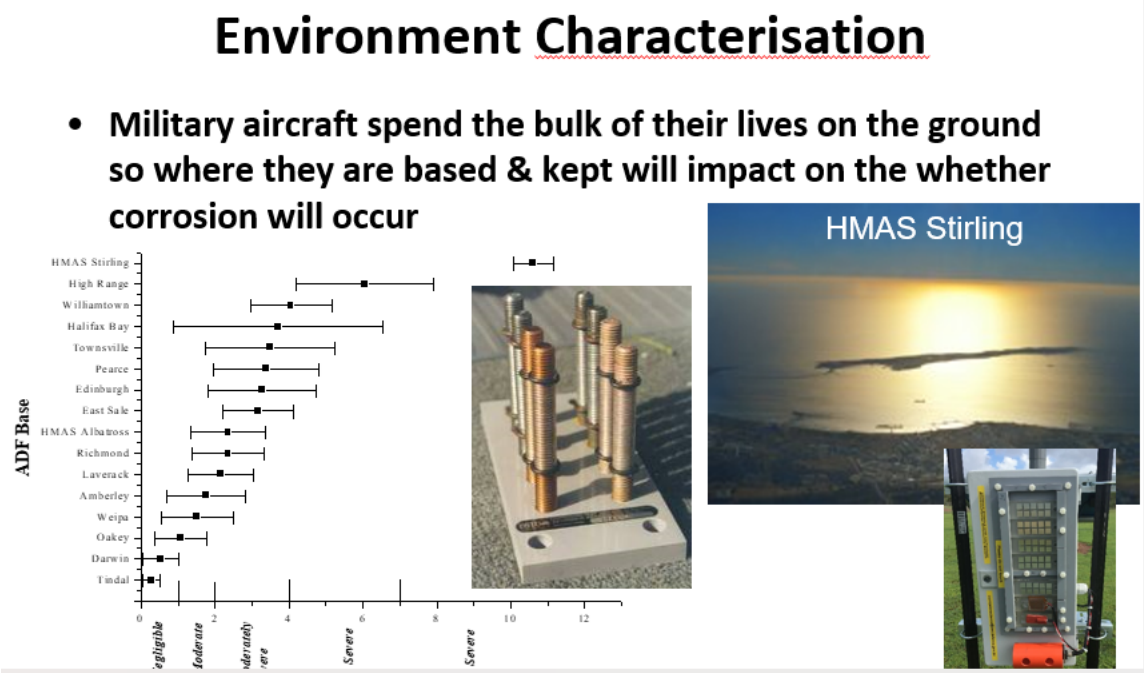
The performance from best to worst was:

1. **Cr primer**
2. **"Green" Pr primer equivalent to Cr primer + top coat**
3. **"Green" Pr primer + top coat**

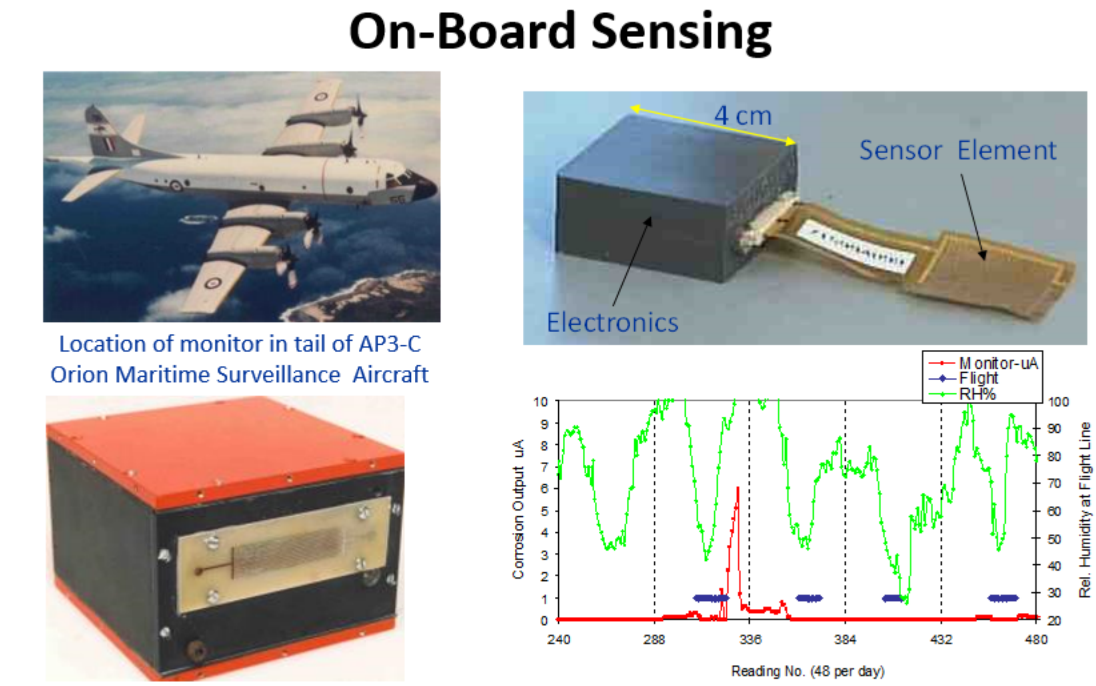
Best available systems of the day could not match Cr primer performance

One very interesting and revealing finding is that when non-chromated topcoat is applied, a very counterintuitive effect occurs, which is that the primer only, over the converted surfaces combination, outperforms the combination that contains the topcoat.

We applaud the Australian government's interest in further developing technologies that will establish the effect of the environment on aircraft at operating locations. This technology coupled with others we will describe herein can be valuable in future aircraft aluminum substructure.



And with Onboard Sensors:



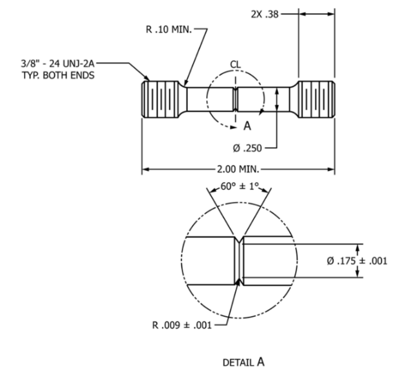
And with Salt Accretion Testing and effects of natural and human-induced water exposure:

We will provide recommenations at the end of this report on integrating these techologies with others presented in this event with an intent to reduce the corrosion rates in aluminum interal substructure.

4.1 PAPER 1: A TRADE-OFF BASED ASSESEMENT STUDY ON POSSIBLE COATING ALTERNATIVES FOR ARMORED COMBAT VEHICLES

A. SELVİ, B. ÇETİN, N. DURLU, FNSS Savunma Sistemleri AŞ, R&D Center, 06830, Ankara, Türkiye, TOBB University of Economics and Technology, Dept. of Mechanical Engineering, 06560, Ankara, Türkiye

The paper and presentation provided information and testing data that shows that Hydrogen Embrittlement of existing corrosion pre-treatment processes as well as that produced by the process of corrosion itself, must be taken into account on lifecycle durability of mechanical components. The documentation presented empirical proof of the Hydrogen Embrittlement characteristics that were found during ASTM F519 standard testing:



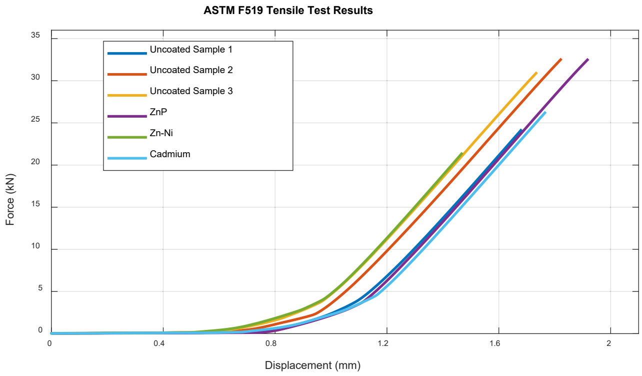


Figure 3.a) Tensile test specimens **Figure 3.b) Disp. vs. force data of the specimens**

The above figures show the influence of the different types of coatings on the mechanical response of the test coupons identifying the effect.

4.2 PAPER 2 : REPLACEMENT OF CHROMATED PROTECTIONS ON ALUMINUM STRUCTURAL PARTS AT DASSAULT-AVIATION

Joy ROMAN, Corrosion Protection specialist, Dassault Aviation, 54 Avenue Marcel Dassault, 33700 Mérignac, FRANCE

This paper describes some of the work Dassault is doing in aviation to qualify non-chromated primer. The discussion focuses around findings on compatibility between specific non-chromated primers and describes the testing processes utilized to evaluate their efficacy.

The work performed by Dassault evaluates Sulfuric Acid Anodise coatings with Ecoat and determined that the most effective combinations are:

Two solutions are qualified:
- Ecoat on all part when there is no friction → Ecoat thickness have to be taken into account to allow assembly
- SAA NC + CrIII post-treatment (touch up) + temporary protection when there is friction

This work presents practical options for the aerospace industry on the utilization of Ecoat as potential choice and identifies the corresponding compatible pre-treatment.

4.3 PAPER 3: DEVELOPING HEXAVALENT CHROMATE FREE COATING SYSTEMS AND IMPLEMENTATION CONSIDERATIONS REGARDING THE USAF T-38 TALON

Paul N. Clark, Ph.D., Sr. Program Manager, Southwest Research Institute (SwRI), Diane Buhrmaster, Engineer, Aerospace Coatings-Air Force Research Laboratory, DAF, Vance Bowman, T-38 ASIP Manager, USAF, Bradley Clark, T-38 Chief Engineer, USAF, SMSgt Bandele Howes, Aerospace Systems Superintendent, HQ AETC/19 AF/A4

The T-38 program in combination with the AFRL performed testing evaluation of non-chromated material combinations that would comply with MIL-PRF-32239B. What they found was that in contrast with Hexavalent Chrome based systems, you could mix and match between any compliant pre-process, primer, and topcoat, but that however, on non-chromated materials, these could only be approved in specific compatible combinations as a system to include specific pre-treatment, primer and finish material specification combinations as follows and adopted System 8 for T-38.

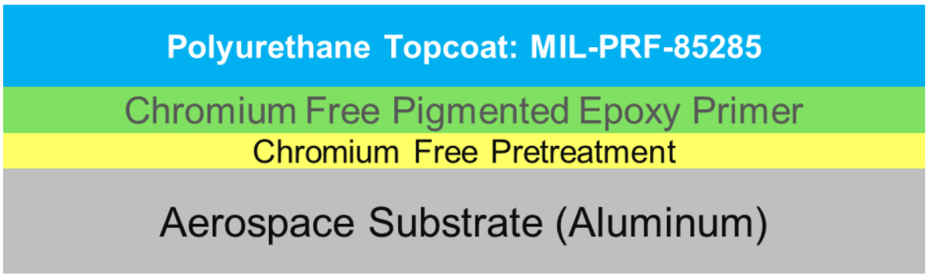


Figure 4: Chromium Free Coating System Notional Schematic

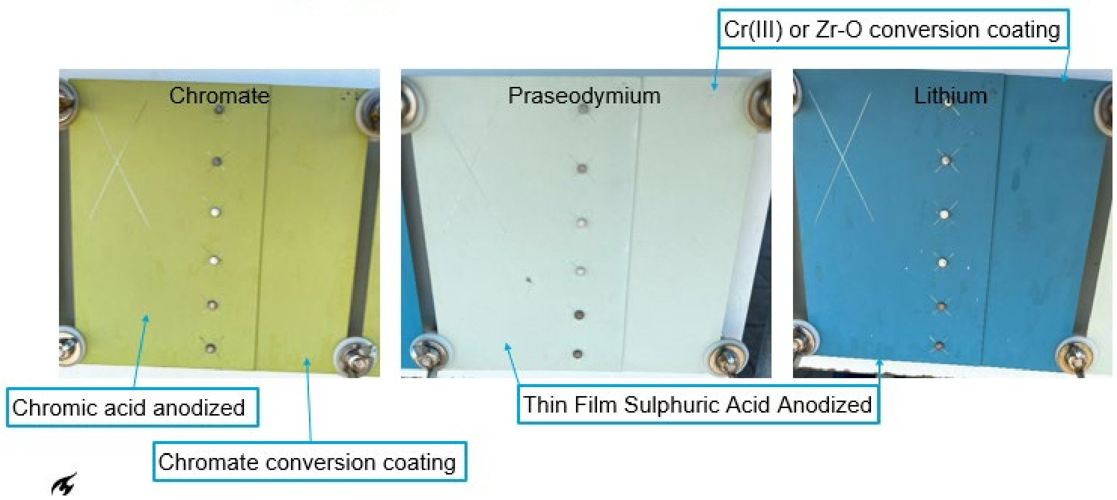
Table 1: Hexavalent Chromium Free Coating Systems Approved by MIL-PRF-32239B

System	Pretreatment – Chromate free	Primer – Chromate free	Topcoat
Coating System 1	PreKote®	AERODUR 2100	99GY001
Coating System 2	PreKote®	AERODUR 2100	AERODUR 5000
Coating System 3	AC-131	AERODUR 2100	AERODUR 5000
Coating System 4	DesoGel® EAP9	CA7236	CA9311
Coating System 5	AC-131	AERODUR 2118	CA9311
Coating System 6	AC-131	AERODUR 2118	AERODUR 5000
Coating System 7	PreKote®	AERODUR 2118	CA9311
Coating System 8	DesoGel® EAP9	CA7236	CA9800

4.4 PAPER 5: PERFORMANCE OF ACTIVE PROTECTIVE AEROSPACE COATINGS IN OUTDOOR EXPOSURE AND IN-FLIGHT TESTS

Arjan Cornet RFDUT, Netherlands, A.M. Homborg, L. 't Hoen-Velterop, J.M.C. Mol.

This paper demonstrates comparative pre-coat and finish combination performance of two non-chromated alternatives to conventional pre-treatments and finish. The results for the below configurations yielded that the Cr(III) and Praseodymium and Cr(III) and Lithium combinations performed better than the conventional types with the Lithium finish performing better than all. This opens the door for additional final testing to provide final recommendations.



TESTING FOR PROTECTIVE FINISH QUALITIES

4.5 PAPER 6: IMPROVED CROSS-CUT ADHESION MEASUREMENT USING COMPUTER IMAGE PROCESSING, CHRIS HAWKINS, DSTL, UK (ADHESION TEST STANDARD EXPLANATION)

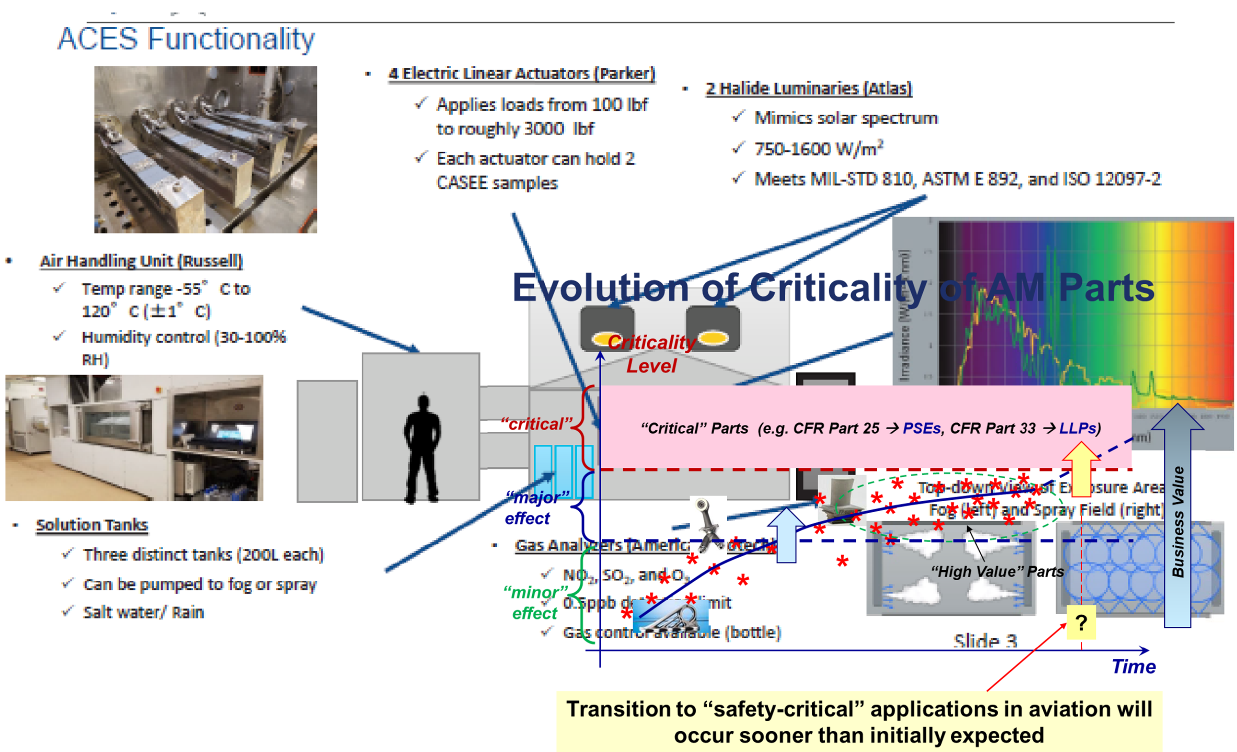
Chris Hawkins, Spencer Court & Nicola Symonds, University of Southampton, UK

This paper described the standard methodology utilized in the UK to measure peel-off strength of coatings and coating combinations. Our observations are that the test could potentially be adopted internationally as it appears to be a very effective test for those purposes in providing comparative tests between proposed non-chromated material performance as compared to chromated legacy materials.

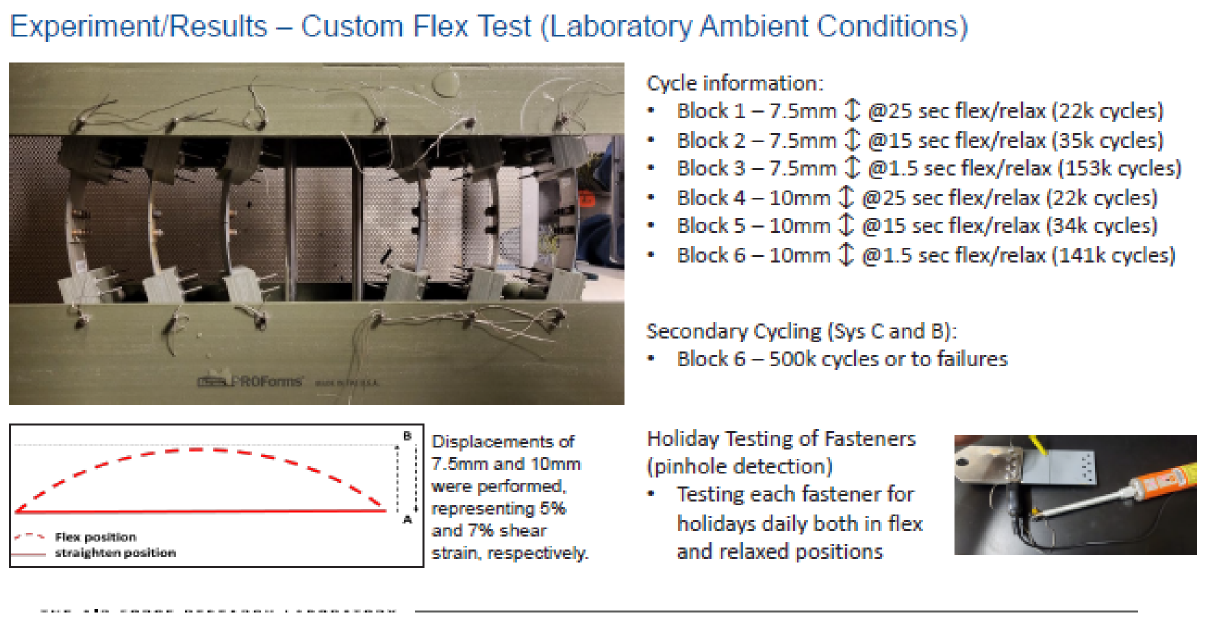
4.6 PAPER 7: DEVELOPMENT OF COMBINED-EFFECTS TESTING AT AFRL

Dr. Chad Hunter, U.S. Ai r Force Research Laboratory (AFRL/RXNMD)
Co-authors: Mr. David J. Borth *, Dr. Douglas C. Hansen * ,
Dr. Matthew I. Hartshorne* * Mr. Matthew J. Rothgeb*,
Mr. Drew M. Sanders*, Dr. Nicholas S. Wilson* *
*University of Dayton Research Institute, USA
* *U.S. Air Force Research Laboratory

The paper describes the various combined testing effects that can be simulated in the ACES Chamber at the AFRL facilities at Wright Patterson AFB in Dayton Ohio:



In addition to all the combined effects that the chamber and loading jigs can simulate, one very important capability for being able to appropriately compare the effectiveness between coating types, which can be useful to determine how well a proposed non-chromated material will perform in regards to paint cracking is the fixture that applies custom flex test bending in varied amounts and conditions.

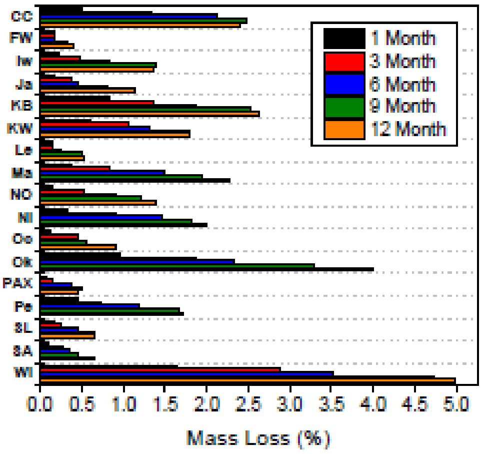


4.7 PAPER 10: LOCAL CORROSIVITY CLASSIFICATION AND ENHANCEMENT OF CORROSION RATE VIA ENVIRONMENTAL MODIFICATION

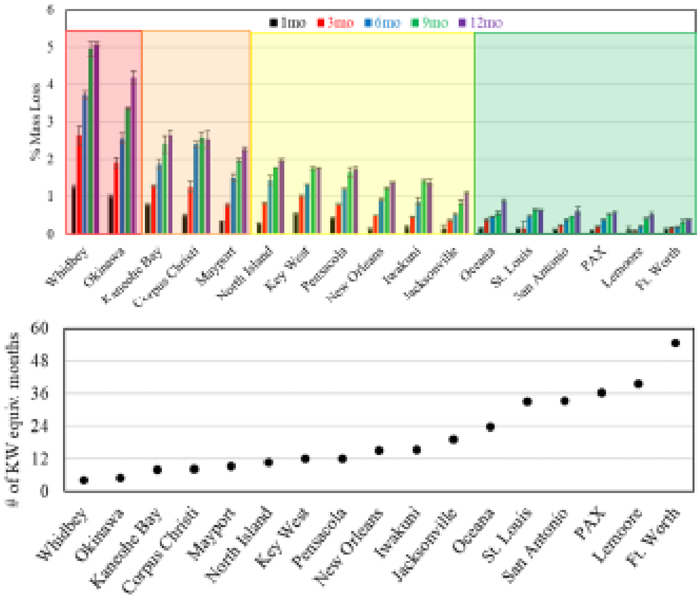
Christine Sanders, Raymond Santucci, Christina Stewart, Center for Corrosion Science and Engineering, U.S. Naval Research Laboratory, Code 6130, 4555 Overlook Ave. SW, Washington, DC 20375

The research associated with this paper set out to determine if the corrosion severity environment at the NRL test site in Key West could be utilized to predict the levels of corrosive severity at other places in the planet based on length of exposure. The results showed that an equivalency could be established per the below charts. This information can now be utilized to predict corrosion progression rates for systems operating at any of these international sites based on testing results at the NRL Key west facility.

This research is valuable in that the NRL can now confidently test at Key West and be able to associate the corrosion rates there to how the corrosion progression rates will occur at these other international locations.



Sites were ranked and sorted by severity and normalized against KW to determine equivalent time for 1 year mass loss



SENSORS FOR PREDICTIVE CORROSION

4.8 PAPER 11: USE OF ENVIRONMENT AND CORROSIVITY MONITORING TO CHARACTERIZE BASE AND AIRFRAME SEVERITY, FRITZ FRIEDERSDORF, LUNA LABS

Fritz Friedersdorf, LUNA Labs

This paper presented the work Luna Labs has been performing in support of NAVAIR to catalogue more closely the corrosivity levels either with on-board sensors or at operational locations utilizing the legacy Luna sensors which measure relative humidity, time of wetness, and material mass-loss.

However, a most revealing and interesting type of technology that Luna Labs has developed are sensors that pair up galvanically dissimilar metals to measure the levels of conductance when droplets of electrolyte from the environment wherever these sensors are located. These sensors are fabricated with only two dissimilar metals in pairs as follows: Titanium and Aluminum, Stainless Steel and Aluminum, and Carbon (to simulate carbon epoxy laminate) and Aluminum.

The data obtained shows the relative galvanic corrosivity environmental qualities as compared at different operational bases, and consistently shows the maximum galvanic interactional detrimental effect is coming from the carbon in the Carbon Epoxy galvanic coupling sensor.

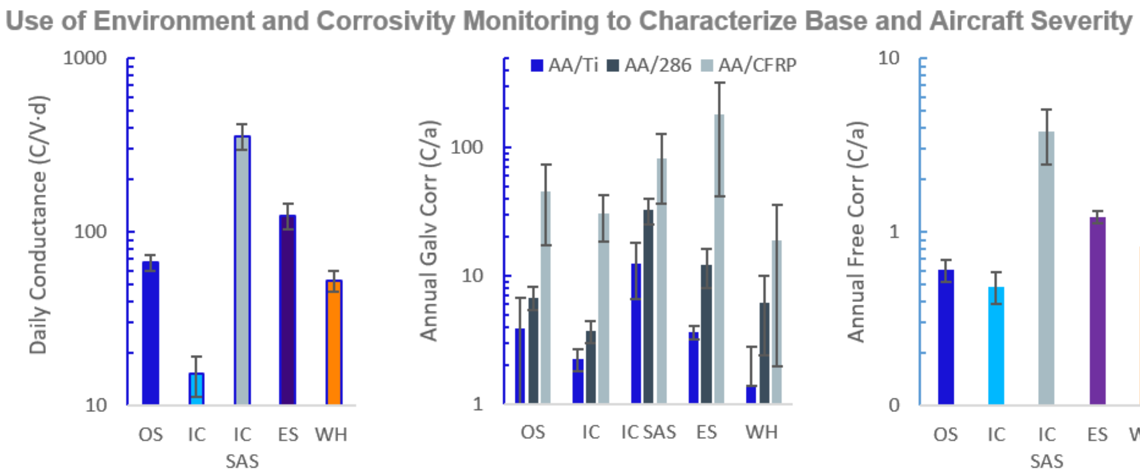


Figure 4. Severity monitoring device results for daily conductance, galvanic corrosion, and free corrosion (left to right). Error bars are 95% confidence intervals.

This technical reviewer believes that the most frequent and severe corrosion on current aircraft design that pair up all these materials together, occurs in the fastener hole Aluminum cross section, developing this technology further in the direction of measuring the levels of conductance that the local electrolytes may have in those fastener holes for the onslaught and progression of corrosion can be highly valuable.

Further development of this technology in combination with other technologies presented here, which I will summarize at the end of this document describe recommended paths.

4.9 PAPER 15 : SALT CONTAMINATION MEASUREMENT AS A TOOL FOR ENVIRONMENTAL DEGRADATION MANAGEMENT

Alison Wythe, Andrew Butler, Peter Trathen and Chris Loader, Defence Science and Technology Group (DSTG), Australia

This paper presents the work that the Australian Government has been doing to identify the effect of the environment on Aluminum structural corrosion on aircraft in Australia. They have designed an array of sensors that measure relevant environmental factors for prediction of pitting corrosion. They have then, experimentally derived pit initiation probabilities and growth rates combined with measurement of local environment to predict corrosion.

DSTG developed a sensor suite and data logging capability (Ground Base Station) to monitor local environments to develop a correlation between the severity of corrosion on the ground with the environmental measurements. They have then measured the actual levels of deposits on aircraft surfaces to establish a correlation with the levels of salt deposits to the measured environmental values.

They have further evaluated the effect on salt deposit reductions based on natural rain events, maintenance clear water rinses and aircraft washes making an important discovery that simple clearwater rinsing without specific intent and design is not very effective in removing salt deposits.

This technical reviewer believes that this particular technology in combination with that of presentation Nr. 11 can be combined to more accurately predict corrosion frequency and severity of Aluminum substructure in fastener holes as I will describe in my summary and recommendation at the end of this technical report.

4.10 PAPER 16: SALT, HUMIDITY AND AIRCRAFT WASHING, GAINING A BETTER UNDERSTANDING HOW TO MITIGATE THE RISK OF SALT INDUCED CORROSION

Patric Helbig, 1710 Naval Air Squadron, UK MOD

This paper presents the work that the UK government has done in determining effectiveness of wash and clear water rinsing methods on the removal of salt deposits from aircraft. They evaluated three different types of salt measuring sensors and selected the most efficient one, the Hedon Salt Meter.

Measuring Salt Contamination

Bresle Method	Elcometer 130	HedoN Salt Meter
Risk of damage from needle Many steps Consumables required Leaves adhesive residues ~5-10 mins per test	Low cost Easy to operate Consumables required No electronics on aircraft ~3 min per test	Higher acquisition cost Easy to operate Only H_20 required as consumable Needs to touch aircraft ~2 mins per test

They found that acceptable levels for a clean/washed aircraft would be at around 20 mg /m2 and tolerable salt level is 50 mg/m2 (short term).

Though this is great work in that getting to understand the levels of salt deposits prior to and before wash intervals to determine both, it is important to note that a secondary effect of attempting to remove the salt in this way, a salt brine will be created that if it pools in the internal belly areas of the aircraft, it can to into the fastener holes creating galvanic corrosion there especially if highly galvanically incompatible materials such as Titanium, Stainless Steel, and Composites are in proximity with Aluminum. I see more value of this type of program on aircraft that are of an all Aluminum construction, not those that have composite panels.

However, there is high value to this technology because it is important to understand the amounts of deposits on aircraft at all times as it is the main input to fastener hole corrosion, as the brines can also enter from under the fastener heads on upper surface panels.

4.11 PAPER 13: CORROSION DETECTION AND MONITORING FOR PROACTIVE AIRCRAFT MANAGEMENT

Lucy Li[1*], Ravi Prakash[2], Mounia Chakik[2], Shiva Ashoori[2], Eyal Rosesheter[3], and Jingwen Guan[4]

[1*] Aerospace Research Centre, National Research Council Canada, Ottawa, CANADA

[2] Department of Electronics Engineering, Carleton University, CANADA

[3] Department of Physics, Carleton University, CANADA

[4] Security and Disruptive Technologies, National Research Council Canada, Ottawa, CANADA

This Paper describes very highly technical work with nanotechnology sensors of various corrosion influential parameters and provides for various promising possibilities for future on-board measurement and reporting nanotechnology.

The ongoing work being done by the Canadian government in the utilization of combined nanotechnologies for sensing relative humidity, time of wetness and corrosion byproducts is very important work that should continue as these provide very viable options for onboard corrosion sensing devices due to their size and eventually non-wired reporting capabilities.

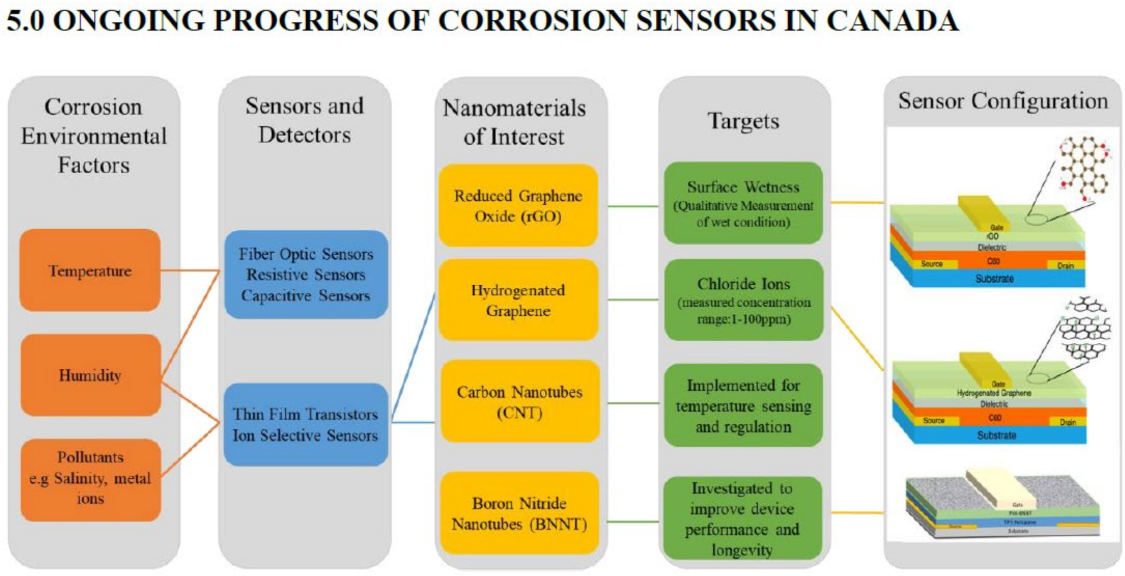


Figure 9: Current approach to creating a nanomaterial-based sensor node for detecting multitude of corrosion environment analytes and corrosion by-products.

4.12 PAPER 14: CORROSION PREDICTION FOR HELICOPTER APPLICATIONS FOR MAINTENANCE

Patricia Miranda Dias(1), Jose Bolivar-Vina(1), Dr. Ludmila 't Hoen-Velterop(2), Capt. Ing. Jörgen van Es(3), David Sinopoli(1)

(1) Airbus Helicopters
Aeroport Marseille provence
13725 Marseille provence
FRANCE

(2) Netherlands Aerospace Centre NLR
Anthony Fokkerweg 2
1059 CM Amsterdam
NETHERLANDS

(3) Material and IT Command
Ministry of Defense
3509 BB Utrecht
NETHERLANDS

This paper describes technology being developed between Airbus, France and the Government of the Netherlands via the use of Luna Sensors in specific locations to determine corrosive environment levels on metallic components. This technology evaluates the levels of humidity, time of wetness and mass loss that occur based on the actual helicopter functionality and its effect on the parameters for exposure causing corrosion related sensor mass loss and describes findings in specific helicopter areas of interest.

Figure 1 : sensors installation on the ship (hangar/flight deck) and on the Helicopter (upperdeck/cabine)

The paper also provides a comparison of corrosivity based on helicopter shipboard location based on conductance measurements of electrolyte on sensors:

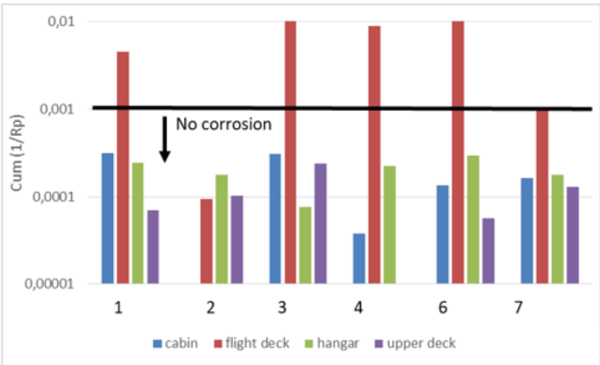


Figure 24 : comparison of the cumulative values of the gold conductance in function of configuration and location

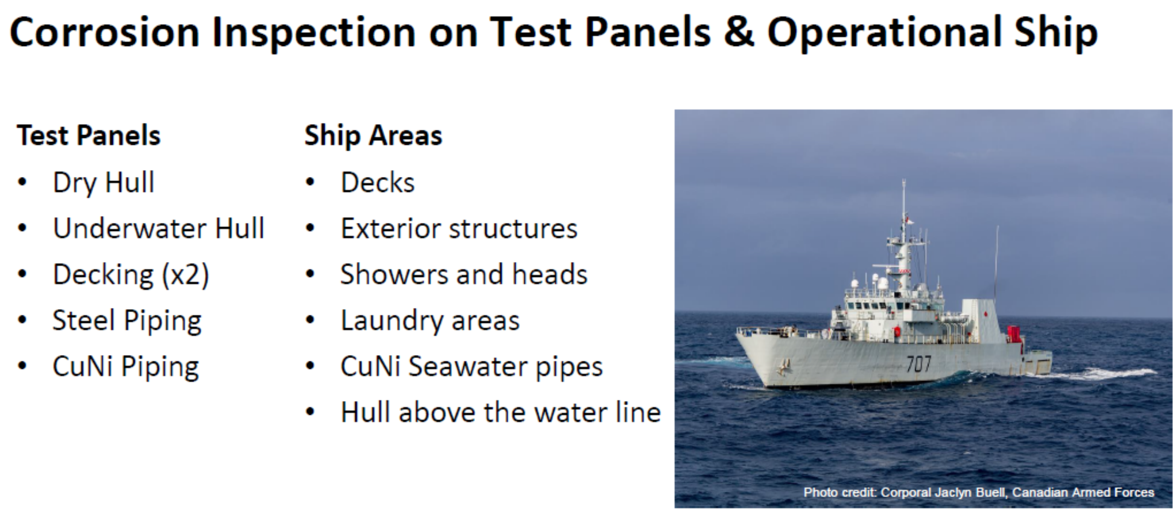
One of the very promising technologies described here is the use of the latest generation Luna sensors for updated information, to include galvanic interaction conductance measurement Luna sensors. Further development of this technology is described in paper nr. 11. We recommend this technology be combined with other specific technologies and methods presented in this paper for future corrosion reduction in aluminum substructure at panel attach fastener holes.

NON-DESTRUCTIVE INSPECTION/TESTING

4.13 PAPER 17: IDEAS CORROSION DETECTION IN SHIPS AND SANDBOX. TECHNOLOGIES DEMONSTRATED AND NEXT STEPS

Dr. Shona R. McLaughlin, Innovation for Defence Excellence and Security, Department of National Defence, CANADA

This paper presents the results of an evaluation of various NDI technologies for inspection of specific areas on ships that are affected by corrosion for which there is a need for faster and less intrusive NDI requirements. The technology focused on certain specific problem type areas, Decks, Exterior Structures, Showers and Heads, Launry Areas, CuNi Seawater pipes and Hulls above the water line. They tested directly on ship areas wherever possible, and performed NDI on sample test panels as well:



It focused on the following technolgies to determine their effectiveness and ease of inspection as unconventional approaches compared to the conventional methods listed below:

Inspection Technologies Demonstrated

Conventional Approaches

- Eddy Current, Pulsed Eddy Current
- Ultrasonic Testing, Phased Array UT
- Magnetic Flux Leakage

All solutions at TRL 9
(proven commercial solutions)

Unconventional Approaches

- Passive Magnetic Field Sensing
- Thermal imaging / Thermography
- Capacitance imaging
- Hyperspectral imaging + AI / DL
- Optical Imaging + AI / ML
- Drone-mounted UT
- Impulse Excitation Technique

Solutions ranged from TRL 5 (early prototypes) to TRL 9

In conclusion, all the technologies evaluated give some level of promise for future practical application, some require much more development and others less, but none were readily practical in their current state. Therefore our recommendation is for the organization presenting to either continue to evaluate other technologies that are closer to a practical solution or select from within these tecchologies presented to invest in further development towards obtaining direct practial application capabilities.

4.14 PAPER 18: COMPARISON BETWEEN NDT METHODS USED TO FIND CORROSION ON AIRCRAFT STRUCTURES

Patryk Ciezak, AFIA, Poland.

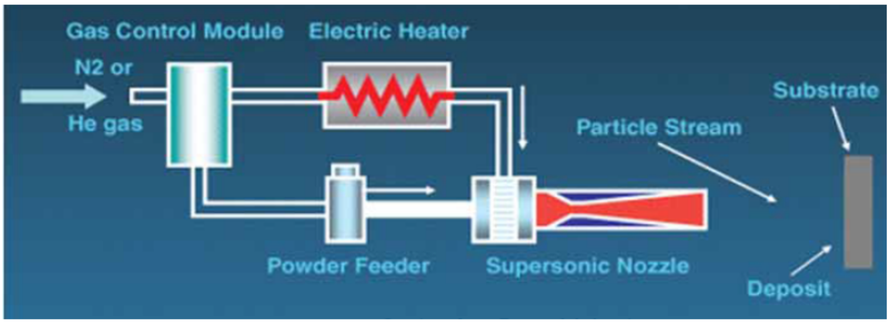
This presentation presented various NDI Techniques to identify corrosion on various configurations of corrosion and provided Structural Prognostics Health Management (SPHM) methodologies for mitigation of corrosion.

CORROSION REPAIR METHODS

4.15 PAPER 19: CORROSION REPAIR USING COLD SPRAY TECHNOLOGY

Matthew Chu, Fredrick Lancaster, Luc Doan, Stoney Middleton. Materials Engineering Department, Fleet Readiness Center Southwest (FRCSW), Naval Air Station North Island, San Diego, CA 92135

This paper presented NAVAIR's historical development and current capability status of Cold Spray processes as an option in repairing material loss on various materials that can include material loos as a result of corrosion pitting and blending. The process is depicted below:



Speed: The powder is injected in a supersonic heated gas stream (like a rocket nozzle but without combustion) and accelerated to ~2600 mph (about Mach 3.5 at sea level).

Acceleration: The drag of the particles makes them accelerate into the flow. The faster the gas, the faster the particle.

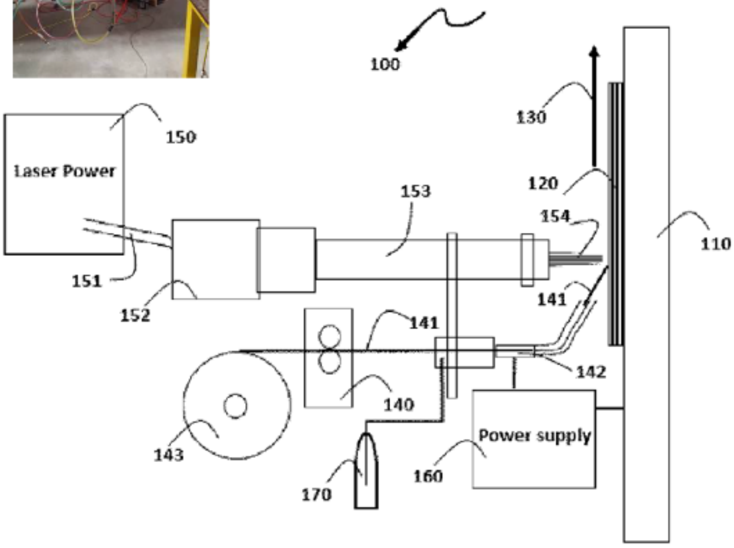
NAVAIR has already approved the Cold Spray process for approximately 150 parts with great functional success. However NAVAIR continues to perform research for it's application on aircraft structural parts. This technical reviewer recommends further investment in the development of this technology for applicability on structural parts with material loss due to corrosion. Much important work will need to be performed on the effect of strength restoration as well as fatigue durability on this subject so that this technology can have more structurally significant value.

4.16 PAPER 20: STATE OF THE ART LASER ADDITIVE MANUFACTURING TECHNOLOGY FOR CORROSION REPAIR APPLICATIONS

James Huang, Department of National Defence, CANADA and James Chen, Natural Resources Canada, CANADA.

This presentation presented the work these organizations had performed in developing and qualifying a state-of-the-art no-preheat hot wire-based laser additive manufacturing repair process using the addition of ER100S-1 wire with laser heat application technology.

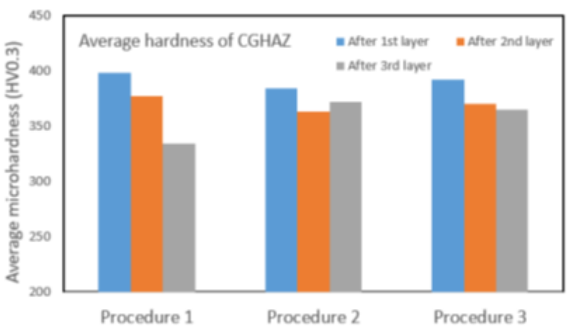
Laser additive process and set-ups

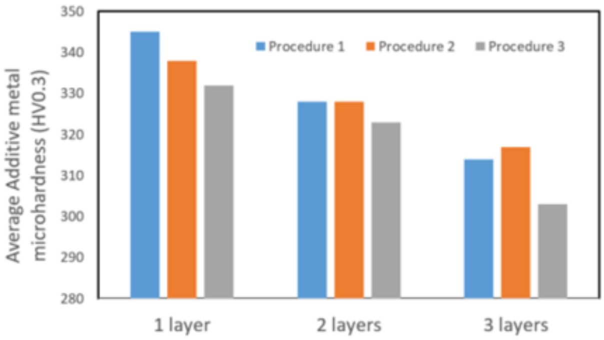


Base material		HY-80
Laser Power (kW)	Set	3.8
	Min.	3.5
	Max.	4.0
Laser Spot Size (mm)		6 x 6
Laser Defocusing Distance (mm)		0
Spoolarc95 filler wire diameter (mm)		1.2
Wire Feed Speed (m/min)		Varied
Laser Beam Traverse Speed (m/min)		Varied
Shielding gas (l/min)		Ar (23)
Shielding torch cup diameter (mm)		19
TIP-TIG wire stick-out length (mm)		50
Hot Wire Current (A)		100
Clad Track Offset (mm)		Varied
Preheat Temperature (°C)*		No preheat
Interpass Temperature (°C)*	Max.	150
	Min.	Room temperature

The results showed that the laser wire material application resulted in better repaired material qualities with less affected Heat Zone deterioration making the new technology an immediately practical application repair process for Submarine repair applications.

Microhardness of HAZ and Additive metal





Summary of the additive metal mechanical properties

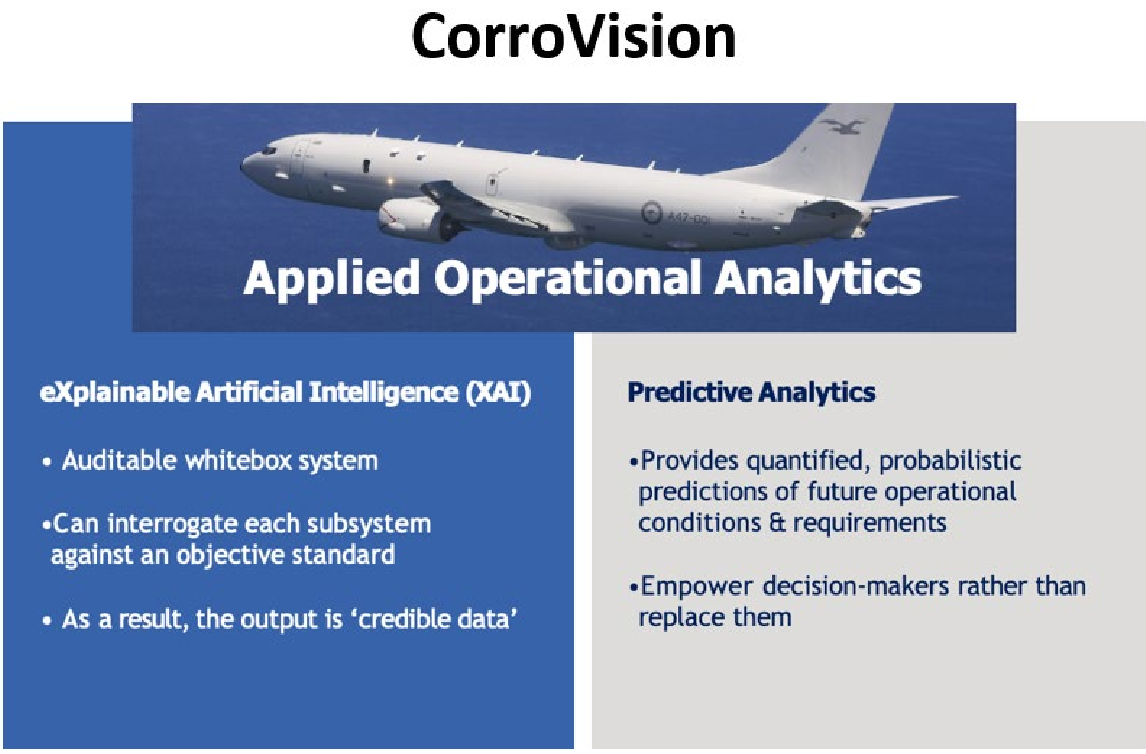
	Welding process	Fillier wire	Yield strength (MPa)	Tensile strength (MPa)	Elongation (2") (%)	Chary V-Notch (J at - 51°C)	Reference
Weld metal	GMAW	Spoolarc 95	655	725	23	88	ESAB
Additive metal	Laser hot wire	Spoolarc 95	881	885	21	128	Current work
Weld metal	SMAW	Electrode F	644	751	28	less than 100	Ritter and Dixon, 1987
Weld metal	GMAW	ER100s	600	752	24	125	Sampath and Varadan, 2006

IMPORTANT FIELDS OF CORROSION WORK

4.17 PAPER 4: MAINTENANCE ORIENTED CORROSION SEVERITY FOR AIRCRAFT PREDICTIVE MAINTENANCE TOOL – CORROVISION

Nabil Humphrey & Darren Roles - Australia.

This presentation provided a detailed explanation of the technology developed by the Australian organization in utilizing Artificial Intelligence and big data analytics type of analytical processes to create algorithms of maintenance data bases focused on specific types of problems affecting fleet maintenance, for example on corrosion maintenance to determine more efficient inspection and repair intervals while maintain existing or better than existing material condition. The analytical system is a reliability centered maintenance type analytical process called Corro Vision which functions as per the below explanation:



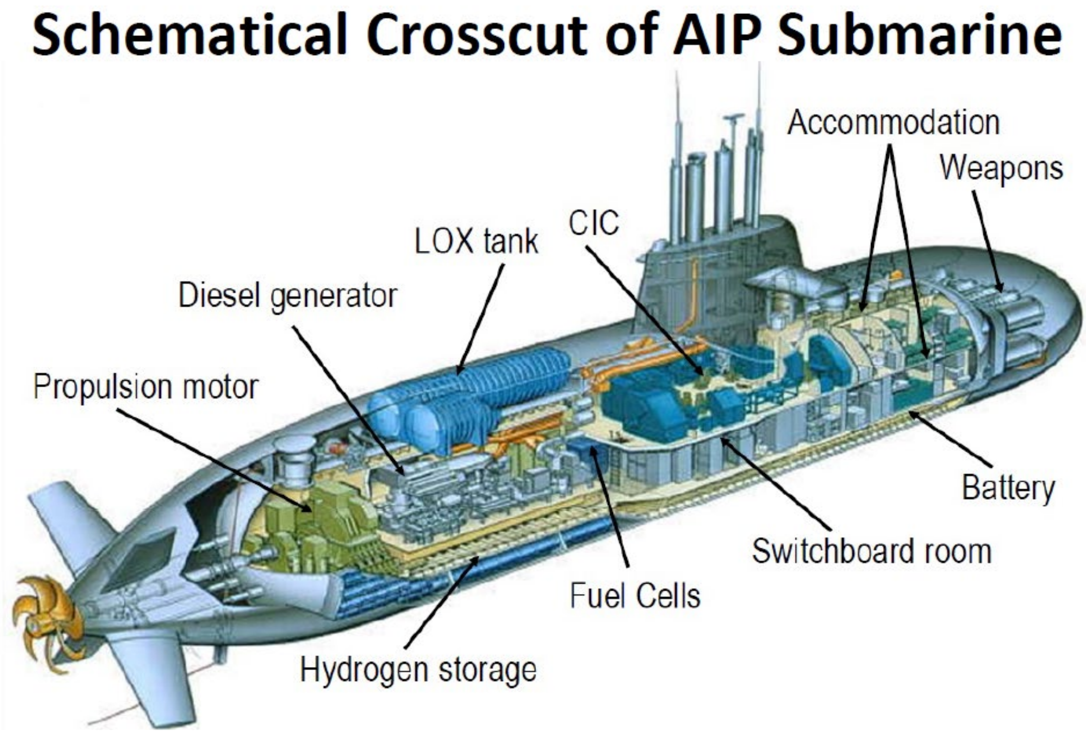
The methodology was utilized on the P3 Orion Australian fleet to determine appropriate maintenance schedules resulting in a longer inspection interval creating maintenance cost savings.

This reviewer recommends further development of this analytical methodology to account for more specific corrosion problems such as corrosion of aluminum substructure in fastener holes for aircraft that have composite panels for which the galvanic interactions between the materials in the stack up result in quite significant corrosion deterioration. The technology should also focus on maximizing of aircraft availability based on corrosion mattters.

4.18 PAPER 8: EFFECT OF SUBMARINE PROPULSION ENGINE COOLANT ADDITIVES ON THE CORROSION OF ALUMINUM SURFACES

S. Kalligeros1, P. Adonakos, N. Melanitis, P. Paraskevas, Hellenic Naval Academy, End of Hadjikyriakou Avenue, 18539 Piraeus Athens; Hellenic Army, 71st Airmobile Brigade, Nea Santa, Kilkis, Greece

This presentation detailed a study that was performed on the propulsion motor cooling system of a submarine to determine the specific types of additives and relative combinations that will minimize corrosivity of the cooling system:



The study found that the best combintion of addtives were of two types and that the optimal ratio of additives in the propulsion motor's cooling circuitis is 4%vol. anti-corrosion additive and1% vol. antimicrobial additive.

These findings are specific to the particular type of engine evaluated, but the investigative methodologies are valuable for any other type of engine in submarines or other vessels with similar cooling systems.

Our recommendations are to apply these investigative methodologies across as many seabased vessel propulsion cooling systems as applicable.

4.19 PAPER 9: MIL-STD-889 AND THE IMPACTS ON CORROSION PREVENTION

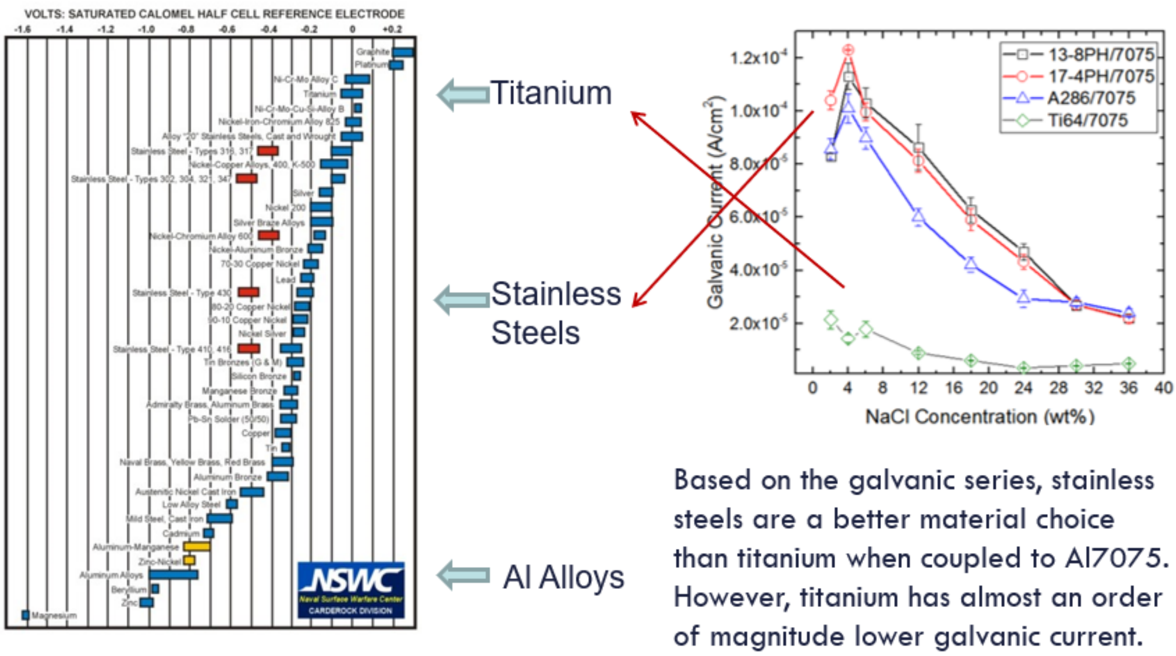
Rachel Black and Rachel Cusic, NAWCAD, United States of America

This paper describes a major revision to MIL-STD-889, the main design standard that at least U.S DoD aircraft Original Equipment Manufacturers (OEM)s are required to follow in determining their choice of materials for galvanic compatibility. While the old standard was based on voltage potential differences per the below graphic:

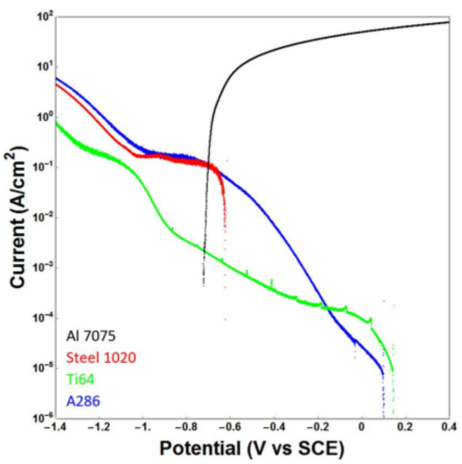
Where the design and manufacturing activities were required to select materials that were as close as possible from each other and if they were on opposite sides of the graph, then they were required to be plated with a compatible material, or other specific galvanic prevention processes and materials were required to be used in conjunction with the material choices.

The revision now includes major breakthrough information that describes the galvanic activity between dissimilar materials to be a function of the interactions between the current density properties of the materials in proximity to each other in the presence of an electrolyte.

Below is a pictorial description of the galvanic interactions between A286 CRES and 6Al4v Ti an 7075Al showing that utilizing Ti yield better compatibility than the CRES in contrast with what the potential diagram would show:



And the below graph shows how the current density interactions between the materials substantiate these findings.



This is a very important subject to this Technical Evaluator because as a result of these findings, there have been developed analytical finite element model software tools that make use of 3D solid modelling technology to analytically calculate not only comparative corrosion compatibility calculations, but also absolute time-based corrosion growth predictions. The latter opens the door for these tools to be utilized in corrosion incidence and growth predictions that can eventually be utilized for maintenance schedule planning but more importantly for fatigue crack generation and growth predictive analytics that will finally include the effect of corrosion.

We provide more detailed recommendations on utilizing these analytical technologies with a combination of other technologies presented in this session to develop a comprehensive and practical solution for aircraft Aluminum substructure corrosion predictive methods for the purpose of obtaining accurate corrosion predictive methods.

5. CONCLUSIONS AND RECOMMENDATIONS

The sessions were well attended and very detailed discussion and questions and answer sessions were held. The discussions led to very important in-session technical interchange, but additional interactions between attendees, continuing technical interactions were observed. All in all, the technical sessions served as a very important international corrosion technical interchange. We recommend more frequent such type of international exchanges if at all possible.

In summary, as previously identified, our observation was that the work presented fell into one of these categories:

Chromate Free Adoption Quest: Much work has been done over the years internationally to select, test and define non-chromated material pre-processes, primer, and topcoat finish systems to comply with varying international requirements for compliant standards by defined timelines. Our observation is that very effective work has been done internationally to identify compliant processes and certainly this NATO conference is an effective means by which to provide information mutually or at least point of contact information in achieving compliance. It is also our observation that in general most or all defined options are practically viable in the conditions typically tested, which is in individual material surfaces.

Testing for Protective Finish Qualities: The participants presenting during this event showed very important testing methodologies that do clearly perform real-life material performance testing that will either qualify or disqualify proposed non-chromated materials. And again these testing and evaluation processes utilize the same comparative conditions that evaluate the comparisons typically on surfaces.

Sensors for Predictive Corrosion: Sensor technology is clearly advancing and there is focus on alternative smaller sized nanotechnology in addition to more traditional sensing technology, such as the time of wetness/relative humidity/mass loss Luna type sensors, with either good promise for onboard type sensing systems or for operational site corrosive environment sensing and definition. But the focus on these types of systems is currently to evaluate the effect on generalized aircraft component surfaces.

Non-Destructive Inspection/Testing: The presentations given in these sessions clearly show the interest and vision of the participants to seek more practical, faster, and more accurate inspection results, and again typically on surfaces.

Corrosion Repair Methods: Once corrosion is identified via NDI or visual inspection, current repair methods, such as blending, etc. may require reinstatement of geometrical and/or material properties. The technologies presented provide for viable options. Recommend the work in these technologies continue.

Important Fields of Corrosion Work: The presentations listed in this category are very relevant to development of an understanding of corrosion initiation and growth. Among these the advent of the science that has been applied to determine that the galvanic activity between dissimilar metals are the result of the combined interactions between their current density properties and the composition of the electrolyte in presence of the materials. All work in this section is valuable and should continue, however this reviewer presents the following conclusions and recommendations.

Conclusions and Recommendations

The one point this reviewer made to the team is that it is our observation that we have arrived at identifying equal to, or better than solutions as alternatives to chromated material, but that the one thing that has not been addressed is that for aviation the problem really lies inside the fastener holes in Aluminum substructure under fabrication conditions that put carbon epoxy layers against Aluminum substructure with either Titanium or CRES fasteners. Our experience is that the Original Equipment Manufacturers do not apply corrosion control pre-processing, primer, nor finish inside the fastener holes, and because in many cases there exists water intrusion into the holes, a violent galvanic reaction occurs on the Aluminum substrate. With bare aluminum in the hole walls, in close proximity to bare carbon fibres all around the composite material hole wall, with Titanium of CRES bolts attaching to CRES nutpates on the far side surface of the Aluminum, with some water intrusion into the fastener holes from either the open nut side from water pooling in the belly of the aircraft or water intrusion from under the countersink heads of fasteners on upper surface attach panels, there is a high amount of galvanic current coupling causing heavy damage to the Aluminum substrate at the fastener hole location. Our experience with over 40 years of aviation corrosion identifies that over 90% of aviation corrosion occurs on Aluminum substructure at the fastener hole wall.

Our major recommendation is a fusion between a handful of technologies/projects that were presented during this event:

Further development of the Luna galvanic coupling sensors that measure the conductance of a given electrolyte on an operational location or in any specific aircraft storage location, near the aircraft of interest, thereby combined with the efforts to catalogue corrosive environment at operational international locations, additionally combined with this input from these conductance findings as a measure of the localized environment's galvanic corrosion contributed conductance, in combination with the salt accretion and surface salt measurements technologies is recommended.

The combined concerted single aimed technology combinations described in papers 9. 11, 15 and 16, and possibly 10, with the analytical computational corrosion prediction methods associated with paper number 9, which companies like Beasy and Corrdesa have capability, a concerted focused effort can be made to predict corrosion occurrence, frequency and growth rates, as well as corrosion pit size predictions. Therefore our strong recommendation is to establish a NATO task team to concert these technologies for this purpose.

Additionally recommend NATO AVT focus on mitigation of Aluminum substructure fastener hole corrosion combining the above technologies and, in addition, related water intrusion mitigation technology development and application across aircraft systems. During the final session technical review the submarine corrosion SMEs agreed that the fastener hole corrosion issue was applicable in that field, therefore we surmise it is also applicable in sea based vessel systems.

We agree with a combined and recommend we comply with the request from a large group of attendees coming from Military Aviation and especially from Navy Military attendees that relevant members of this event should hold frequent, possibly biannual online and annual in-person meetings to discuss independent and collaborative corrosion mitigation technology developments, and to group specific technologies in efforts to address direct, most highly impacted corrosion concerns, such as the galvanic corrosion effect described above on aluminum substructure inside fastener holes due to moisture intrusion.