Atmospheric Corrosion Monitoring Technical Exchange Meeting Summary

Second annual virtual technical exchange meeting on atmospheric corrosion monitoring and mitigation strategies

The second annual Atmospheric Corrosion Technical Exchange Meeting (TEM) brought together participants from the naval, aerospace, and offshore wind industries. Hosted by Pierre Morel of Acuity Corrosion Technology at Luna Labs, the half-day virtual event featured presentations from leading organizations, including the U.S. Navy, Northrop Grumman, and Sirris, spanning shipboard and airborne corrosion monitoring, offshore structural health monitoring, and aerospace coating and material performance under combined mechanical and environmental loading. A consistent theme ran through every session: real-time continuous monitoring reveals corrosion behavior that conventional inspection methods cannot detect, and the community is translating those findings into smarter, condition-based maintenance decisions.

Steven Kopitzky, PhD

Corrosion Science Team, Material Protection Technology Branch | Naval Air Warfare Center Aircraft Division (NAWCAD),

Kopitzky presented a multi-year effort to quantify corrosion severity across land-based, shipboard, and airborne environments with the goal of replacing standard practice with quantitative, data-driven maintenance planning.

Ship-Based Monitoring

Maintenance planners in naval aviation apply a 'factor of two' when estimating corrosion severity on ships versus land but without concrete data to support it. Kopitzky's team deployed Acuity LS sensors and coupon panels across five locations on two aircraft carrier classes and three locations on a guided missile cruiser, with exposures up to 14 months, to quantify that relationship for the first time.

The most significant finding concerned the distribution of relative humidity (RH) values. **On land, the conventional 80% RH threshold for corrosion onset holds broadly true. On ships, the majority of corrosion events occurred below that threshold** in conditions that traditional time-of-wetness models would classify as non-corrosive. As Kopitzky noted, this indicates other factors are at play, possibly more aggressive sea spray or changes in conditions unique to the marine environment. As a result, risk models built on the 80% RH threshold will underestimate corrosion exposure time for ship-based assets.

Using a multi-sensor corrosivity scoring system developed with colleague Alexander Lilly (see presentation notes below), exterior ship locations scored approximately 2 points higher than the most aggressive U.S. land site studied. Because the scoring scale is logarithmic, this represents an **~4x increase in corrosivity**, not the 2x that maintenance planners had assumed. This type of quantitative data has the potential to replace rules-of-thumb estimates.

H-1 Helicopter Deployments

Extending the approach to flying assets, sensors were installed on seven H-1 helicopters at two airframe locations per aircraft. Early results were immediately actionable as sensor data identified one location as significantly more corrosion-active than engineering analysis had predicted. A subsequent physical inspection confirmed significant corrosion at that exact location, an early but notable validation that sensor data agrees with maintenance findings.

In a separate finding, when one aircraft relocated to a more aggressive environment, the change was clearly visible in the sensor data. This demonstrates that operational environment changes are detectable in near-real-time, opening the door to adjusting maintenance risk based on where an asset has been operating.

Key Takeaways

- The 80% RH corrosion threshold does not hold for ship environments. The majority of corrosion events occurred below it, requiring risk models for naval assets to be reconsidered.
- Exterior ship locations are ~4x more corrosive than the most aggressive U.S. land site studied, not 2x as maintenance planners had assumed.
- Hangar bay sensors were placed at the wall opposite the bay doors to capture the minimum severity case; any location closer to the doors will be at least as severe.
- Sensor data agreed with maintenance findings on the H-1 helicopter. The more active location identified by the sensors was confirmed to have significant corrosion on inspection.
- Operational relocation to a more aggressive environment is visible in near-real-time sensor data.

Discussion Highlights

The Q&A focused on corrosion activity below 80% RH on ships. Chemical characterization of silver coupon deposits via XPS and aluminum samples via SEM/EDS is underway to investigate whether the driver is sea spray quantity, chloride speciation, or a combination. Discussion also confirmed that transitioning to sensor-only monitoring and retiring witness coupons is an active goal, with the sensor-to-coupon correlation now validated across the full severity range studied. On coating evaluation (not yet pursued in this program), the priority has been establishing a standardized bare-metal baseline, and testing coated coupons in marine environments typically requires 2+ years to produce meaningful results.

Jérika Lamas, PhD

Senior Engineer, Metals | Sirris (Belgium)

Lamas presented the WILLOW project, a European Union–funded initiative to develop sensor-based corrosion monitoring and digital prognosis tools for offshore wind monopile structures. Sirris, a non-profit industry-funded research organization, leads the corrosion monitoring work package, deploying instrumented frames at multiple zones on a test structure off the Belgian North Sea coast.

The WILLOW Project

WILLOW — Wholistic and Integrated Digital Tools for Extended Lifetime and Profitability of Offshore Wind Farms — is a European Union–funded collaborative project involving research organizations, universities, offshore wind operators, and subject matter experts across Europe. Sirris' role is in Work Package 2, characterizing corrosion mechanisms at the monopile level. This data feeds Work Package 3's machine-learning prognosis tools for predicting remaining useful life at wind farm fleet scale.

The Offshore Corrosion Challenge

In the splash zone of an offshore monopile, no cathodic protection is applied. Structural integrity depends entirely on the coating. While coatings are effective, there is currently no reliable method to predict the remaining useful life of the coating or to quantify the structural condition once coating degradation begins. The WILLOW project is designed to understand how corrosion evolves across each zone and build a global structural health monitoring framework from that data.

Test Site and Zone-by-Zone Findings

Instrumented frames were deployed at a monopile-like research structure 500 meters from the coast in the North Sea, accessible approximately every three to four months. Frames at five zones - splash, tidal, submerged external, submerged internal, and mud line – carry bare and coated metal coupons, Acuity LS sensors, and zone-appropriate electrochemical instruments. One of the clearest messages from the first five-month coupon retrieval is that corrosion mechanism and rate differ substantially by zone. Uniform corrosion dominates the submerged sections; the tidal zone shows higher rates driven by cyclic wet/dry exposure; and in the splash zone, pitting is the dominant mechanism, visible as small black dots on the coupon surface and is a concern given the absence of cathodic protection.

Acuity LS in the Splash Zone

The splash zone presents significant challenges for corrosion sensors: rapidly changing electrolyte conditions, intermittent wetting, and salt residue that can produce false signals. Conventional time-of-wetness sensors proved inadequate. After discussion with the Acuity team, the Acuity LS surface conductivity measurement was selected as a viable proxy for time of wetness in this environment. The sensor was deployed on a 'let's see if it survives' basis and after more than 12 months of operation, including a field battery and lid change, it continues to function correctly.

The team used a literature=based approach to calculate a theoretical maximum pit depth. With a **factor of three difference** between the calculated value and measured maximum pit depth, the findings suggest that conductivity, not just humidity, needs to be part of the model.

Key Takeaways

- Corrosion mechanism and rate differ substantially by zone. A single inspection or protection strategy cannot adequately address the whole structure.
- The splash zone, with no cathodic protection, is the highest-risk area; pitting is the dominant mechanism.
- Acuity LS surface conductivity is validated as a viable time-of-wetness proxy in the offshore splash zone, where conventional sensors cannot perform reliably, and the sensor survived 12+ months including a field battery change.
- A humidity-only pitting model overestimated actual pit depth by ~3x; incorporating conductivity is the identified path to a more accurate model.
- Sensor and coupon data from WP2 will feed WP3 machine-learning prognosis tools for coating lifetime and structural remaining useful life prediction.

Discussion Highlights

The Q&A clarified the sensor types used in the tidal zone including an electrical resistance (ER) probe for continuous thickness loss, a CTD sensor for detecting water presence, and a linear polarization resistance (LPR) sensor for electrochemical corrosion rate, allowing two independent techniques to be compared directly. It was confirmed that integrating the conductance signal over time to look for shifts in corrosion regime is planned as the next analysis step. On the pitting calculation: the theoretical cumulative pit depth sums literature-based depth estimates per RH band, weighted by time at each band, yielding a single maximum pit prediction, not a volumetric distribution.

Maria Nelson & Alexander Helmer, PhD

Materials Engineers, Aerospace Sector | Northrop Grumman, Melbourne, FL

Nelson and Helmer presented a two-phase program building on work shared at last year's meeting. Phase 1 established sensor baselines across a benign hangar environment and an aggressive coastal environment. Phase 2 moved sensors onto an operational flying aircraft, producing direct actionable results.

Phase 1: Scoping Study

Before broader deployment, the team set out to validate the sensors. Do they record continuously without data gaps? Does sensor weather data agree with nearby weather stations? A hangar at Melbourne, FL and a coastal location at Kennedy Space Center (KSC) (~800 ft from the ocean) were selected to bracket the severity range. The hangar environment was benign with readings falling below the calibrated threshold. Sensors were initially mounted vertically but after consultation with the Acuity team, they were repositioned to a **45-degree angle**, which immediately produced higher current readings. Even so, half the sensors were eventually redirected to accelerated testing. The KSC sensors showed far higher galvanic current and greater variability, as expected for a coastal marine environment. Galvanic pairings behaved consistently with MIL-STD-889D rankings. Two hangar sensors have now operated continuously for more than two years, providing useful long-term baseline data.

Phase 2: Flying Testbed

Four sensors were installed on an operational aircraft: two in the wheel wells and two in the underside compartment known as the 'canoe'. Three galvanic pairings were tested at both locations to enable direct bay-to-bay comparison under identical flight conditions. Approximately ten months of flight data were presented.
The findings were clear and consistent: **every humid-environment landing produced a measurable corrosion event. Every arid landing produced none.** Single-flight analysis confirmed the mechanism. At touchdown in a humid environment, relative humidity spikes and remains elevated for an extended period, and the galvanic corrosion current rises in parallel and holds. At an arid landing, RH spikes but drops back quickly and the corrosion current shows no response. The aircraft is hangered between flights, making the landing event the primary corrosion driver.

The wheel wells were more corrosive than the canoe, which recovers humidity faster due to its more enclosed geometry. Comparing all three deployment environments — KSC, hangar, and the flying testbed — confirmed expected severity ordering. One notable finding was **the same conductance reading in two different environments does not imply the same corrosivity**. As Helmer noted, conductance spikes of similar magnitude on the aircraft and in the hangar produced different corrosion increments.

Key Takeaways

- Sensor mounting angles matter in low-activity environments. Repositioning from vertical to 45° rather than vertical is important for accurate readings in low-activity environments and produced an immediate improvement in readings.
- Humid landings are the primary corrosion driver on this aircraft. Every humid landing produced a corrosion event; every arid one did not.
- Individual landing events are clearly resolved in continuous sensor data, enabling flight-by-flight corrosion accounting.
- Wheel well is measurably more aggressive than the canoe; the canoe recovers humidity faster due to its more enclosed geometry.
- Equal conductance readings in two different environments do not imply equal corrosivity. Electrolyte chemistry must be considered in addition to the conductance level.
- Findings have prompted a review of environmental severity assumptions in current aircraft maintenance planning.

Discussion Highlights

Discussion raised the question of whether canoe sensors capture the full picture of moisture ingress. Sensors are mounted on the interior wall, not the base, so pooling water may not be captured. The team noted the intent was to characterize minimum corrosion risk at that position. An attendee referenced NLR (Netherlands Aerospace Centre) having made similar findings and changed helicopter maintenance practices as a result, implementing post-flight drying with conditioned air. Thermography was suggested as a complement to sensor data for quantifying total structural moisture content. Unusual dark markings on a long-deployed KSC sensor were also discussed. An attendee noted this is a known phenomenon at coastal sites, and further investigation is planned.

Alexander Lilly

Corrosion Science Team, Material Protection Technology Branch | Naval Air Warfare Center Aircraft Division (NAWCAD),

Lilly presented the development of a modified accelerated corrosion test method for evaluating stress corrosion cracking (SCC) resistance of surface treatments on 7075-T6 aluminum. The goal is to generate baseline SCC performance data for thin-film anodize and TCP conversion coatings, establishing a reference against which developmental replacement coatings being developed at NAWCAD can be compared.

The Test System

The Acuity Insight SL system applies a fixed tensile load to a double cantilever beam (DCB) sample via a spring-loaded fixture. The semicircular notch geometry of the DCB represents half of a fastener hole making it directly relevant to aerospace structures. Displacement and load are monitored continuously; compliance is calculated and correlated via finite element modeling to estimate crack length over time. Up to six fixtures operate simultaneously in a single chamber. The primary metric is **time to achieve 1 mm of estimated crack length**.

Test Development

The standard AMP TM 21559 protocol — cyclic RH at 40°C with two six-hour acidified salt fog events per week — was too severe. At 70% of yield, all surface treatment conditions failed immediately after the first fog event with no differentiation between them. Reducing the load helped modestly but did not solve the problem.

The key adjustment was to the salt deposition. Using Breslé patch measurements on C-22 witness panels, the team found that the standard six-hour fog deposited approximately 1,200 µg/cm² while a 10-minute automated fog deposited approximately 120 µg/cm² — similar to manual swab application but far more repeatable and fully automatable. As Lilly noted, the 10-minute fog as a starting point was based primarily on a hunch, but the data confirmed it put salt loading in the right range. The final modified protocol uses 10-minute fog events every 24 hours at 50% of yield.

Testing across five conditions produced clear separation. Bare 7075-T6 reached the 1 mm crack threshold at approximately 102 hours, confirmed across two experiments. Anodized with hot water seal failed at roughly 30 hours, approximately one-third the time of bare material. TCP conversion coating was the only condition to consistently outperform bare material at approximately 220 hours, roughly twice the bare result. Hex chrome remained in test at 361 hours as the benchmark. Anodized with TCP seal showed high variability across the three samples tested, and Lilly was clear no firm conclusions could be drawn from that condition yet.

Additional Findings

Across all conditions, **crack growth rates increased preferentially during the 60% RH drying hold** in the cyclic test profile. The drying mechanism was identified as critical to fostering crack growth, consistent with prior research. Fractographic analysis confirmed all failures were genuine SCC followed by mechanical overload, consistent across all coating conditions. The team also found that surface preparation chemistry prior to coating, specifically desmudding vs. nitric acid cleaning, produced measurably different SCC resistance on bare substrates, though the implications post-coating remain to be determined.

Key Takeaways

- Standard fog protocols are too aggressive to differentiate between coatings. The modified 10-minute fog protocol delivers a realistic, repeatable chloride dose
- Thin-film anodize with hot water seal shows markedly lower SCC resistance than bare aluminum (~30 vs. ~102 hrs) invisible to conventional visual or pit-count evaluation.
- TCP conversion coating approximately doubled SCC life relative to bare material; hex chrome remains the benchmark.

- The 60% RH drying hold drives crack growth. The drying mechanism, not the wetting event, is the critical SCC driver in this test environment.
- Surface preparation chemistry measurably affects SCC resistance, demonstrating the test method's sensitivity to upstream process variables.

Discussion Highlights

The discussion explored whether anodizing might introduce micro-defects that promote pitting and accelerate crack initiation, considered plausible and a high-priority area for further investigation. The high variability in failure time for anodized + TCP seal samples was discussed; with only three samples per condition, conclusions are premature and more replicates are planned. One finding that resonated with attendees was that the magnitude of the applied load had surprisingly little influence on when and where cracks initiated. The corrosive environment appeared to be the controlling factor. This was supported by an observation in the test data cracks did not always start at the point of highest stress on the sample, which would be expected if stress were driving initiation, but sometimes started off to the side of it.

Carly Cocke, PhD

Research Scientist, Acuity Corrosion Technology | Luna Labs

Cocke presented results from two experimental programs using the Acuity Insight SL (static load) and Insight DL (dynamic/fatigue load) systems, Luna Labs' test platforms for combined mechanical and atmospheric corrosion loading. Both systems fit inside standard accelerated corrosion test chambers and capture the full crack development curve from initiation through propagation to fracture.

Insight SL: Coating Systems for EAC Protection

A structured experiment evaluated two aerospace primer systems — a standard non-chromate primer and an aluminum-rich sacrificial primer — with and without a galvanic crevice former simulating a fastener, tested at two independent laboratories to establish inter-laboratory reproducibility. The **aluminum-rich primer significantly outperformed** the non-chromate primer in crack initiation life. The **galvanic couple significantly accelerated cracking**, confirming that fastener material selection is a critical variable in EAC resistance. Applied stress level had no statistically significant effect. Environmental conditions, not the magnitude of the mechanical load, controlled crack initiation. Results were reproduced between NAWCAD and Luna Labs, validating the method's inter-laboratory reliability.

Insight DL: Corrosion Fatigue and RH Transients

The fatigue testing program explored what happens when an asset transitions between high- and low-humidity environments, directly relevant to aircraft operations. Testing SCC-susceptible 7075-T6 alongside SCC-resistant 7050-T7 as a control showed that i**n 7075-T6, the drying transition itself produced a sharp spike in crack growth rate**. This effect was absent in 7050-T7 under identical conditions confirming it is a genuine SCC mechanism, not a mechanical artifact.

Under cyclic humidity profiles simulating aircraft operational conditions, low RH at altitude, high RH on the ground, **crack growth rate had peaks associated with drying events consistently throughout the tests**. Cocke also noted that crevice geometry can retain moisture after the ambient environment has dried, meaning the conditions at the crack tip may be more sustained than ambient measurements suggest.

Key Takeaways

- Aluminum-rich sacrificial primers significantly outperform non-chromate primers in EAC resistance under realistic test conditions.

- Galvanic coupling at fastener sites dramatically accelerates crack initiation. Fastener material is as important a design variable as the coating itself.
- Applied stress level does not dominate EAC response.
- Inter-laboratory reproducibility was confirmed between NAWCAD and Luna Labs.
- The drying transition, not sustained wetness, drives crack growth rate spikes in SCC-susceptible alloys; SCC-resistant 7050-T7 does not show the same effect.
- Every drying event in a cyclic RH profile simulating aircraft operations produced a measurable crack growth rate peak.
- Crevice geometry can retain moisture after ambient drying. Crack-tip conditions may be more sustained than chamber measurements indicate.

Discussion Highlights

The discussion covered three threads. Is crack growth acceleration under drying related to thin-film corrosion acceleration? Cocke confirmed this is very likely, as drying concentrates the electrolyte and creates more aggressive conditions at the crack tip. On whether crack growth rate decreases reflect crack blunting rather than mechanical behavior, Cocke acknowledged blunting as a plausible mechanism where severe corrosion at the crack tip reduces its sharpness, though the contributions are difficult to separate definitively. On the complementarity of the SL and DL systems, the SL is well-suited for SCC studies. It’s simple, reliable, and well-validated while the DL adds fatigue loading relevant to actual aircraft structural loading with remote load adjustment as a practical advantage. Both are needed; neither replaces the other.

Acuity Corrosion Technology: Product and Technology Updates

Pierre Morel provided an overview of current Acuity technology initiatives, several of which arose directly from customer needs identified through the kinds of field deployments discussed throughout the day.

Environmental Severity Classification

The Acuity team has developed a refined six-category environmental severity framework building on field data collected through NAWCAD partnerships and led analytically by Fritz Friedersdorf and Doug Wall. The framework correlates continuous sensor data — free corrosion, galvanic corrosion, and surface conductance — with measured material response across a wide range of domestic and international sites. A key finding is that the galvanic couple signal maintains a consistent relationship across sites regardless of alloy, providing a reproducible classification reference that can be tied directly to alloy-specific maintenance planning thresholds.

Insight EAC Testing Systems

The Insight SL and DL product lines extend Acuity's capability to combined mechanical-load and atmospheric corrosion testing, supporting both static and fatigue loading inside standard accelerated corrosion chambers. Acuity LS sensors deployed alongside each load frame provide local environmental context for the mechanical test data. Outdoor static-load DCB deployments complement chamber tests with real-world atmospheric exposure data.

Battery Pack for Multi-Sensor Deployments

This capability was developed in response to a customer requirement to deploy multiple Acuity LS sensors in airframe locations where individual battery replacement is impractical. The pack powers multiple sensors simultaneously; sensors can be daisy-chained for unified data acquisition; batteries are individually labeled; and a hot-swap design prevents any loss of power or data timestamp continuity during replacement. Validated on a C-130 deployment.

Remote Cellular Telemetry (Coming Soon)

A cellular telemetry unit is in final development, enabling Acuity LS data to be transmitted automatically over cellular networks to the cloud and accessed through C-DAT software, eliminating the need for manual data retrieval. First units are expected within a few months. Solar power options for off-grid deployments are also under active evaluation.

Acuity Product Portfolio

Product	Description
Acuity LS	Continuous on-board monitoring of environmental and corrosivity parameters
Acuity ES	Continuous corrosivity and environmental record for assessing materials performance
Acuity CR	Autonomous corrosion rate and severity monitoring for coatings and alloy evaluation
C-DAT	Cloud-based data analysis platform; integrates with all Acuity sensors for visualization and reporting
Insight SL	Static-load DCB test frame for SCC and EAC evaluation in corrosion chambers
Insight DL	Fatigue-load DCB test frame for corrosion fatigue and cyclic EAC; load parameters adjustable remotely

Conclusion

Three themes tied the day together. **First**, assumptions must be tested. Fixed humidity thresholds, assumed severity multipliers, and visual inspection as the primary evaluation method consistently fell short when tested against real-world continuous monitoring data. The gap between assumption and reality has direct maintenance consequences.

Second, across every presentation and test method discussed, the drying transition emerged as a critical driver of corrosion damage from ships and aircraft to offshore splash zones and laboratory SCC chambers. As Pierre Morel noted in closing, the consistent importance of humidity drying transients ran through every session of the day.

Third, condition-based maintenance is not a future ambition. It is happening now, across naval aviation, aerospace, and offshore infrastructure. The presentations demonstrated that continuous monitoring delivers insight that no conventional approach can replicate, including counter-intuitive corrosion locations, flight-by-flight accounting, and zone-specific structural risk.

Input Request

The community plans to reconvene for a third meeting. All are encouraged to complete the brief survey here to provide input on planning, including timing, topics, and format.

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