# Continuous Environment and Corrosivity Monitoring for Improved Materials Selection and Asset Management

Presentation for the Joint Technology Exchange Group

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# Luna Labs USA – a specialty products and technology development company

## Who we are

- **1990** – founded as applied research division of Luna Innovations Inc
- **2022** – became independent and privately held
- Headquartered in Charlottesville, VA
- Approximately 90 people
- Multi-disciplinary; development teams in systems engineering, materials chemistry, and biotechnology
- Technology partner to industry and defense organizations

## Markets

- Defense
- Aerospace
- Automotive
- Clean Energy
- Sustainable Manufacturing
- Healthcare
- Emergency Services

## Focus Areas

- Corrosion Monitoring Solutions
- Asset Management and Diagnostics

- Specialty Materials and Polymers
- Industrial Decarbonization
- Sustainable Materials

- Medical Simulation
- Biomedical Devices and Wearables
- Biomedical Materials

# Corrosion Technology BU

## Product Line

Corrosion Monitoring Solutions

**Test and Measurement**
laboratory, outdoor, and on-board evaluations to enhance confidence and performance

**Maintenance**
on-board monitoring to inform corrosion maintenance

## Applied Research

**Measurement Development**
real-time continuous monitoring

**Materials & Corrosion Research**
material performance and corrosion severity classification

**Modeling & Analytics**
design, corrosion diagnostics, and prognostics

# Opportunities for Improved Corrosion Prevention and Control

Adopting **new protective coatings and materials**

- 10 -15 years to introduce new aerospace coating
- Inadequate performance tests
  - Variability
  - Poor discrimination
- Testing does not quantify failure modes of greatest concern
  - Galvanic corrosion
  - Environment assisted cracking

Test and Measurement

Implementing preventative **maintenance practices**

- Challenge to quantify the benefits of new practices
  - Covers, hangers, washing, sealing, and dehumidification

Managing **individual aircraft corrosion** throughout O&S

- Conservative inspection intervals reduce aircraft availability
- Unexpected damage occurs from undetected corrosion

Maintenance

# How Luna Labs is making an impact

Adoption of **new protective coatings and materials**
- Expedite testing and qualification (AMPP TM21449-2021)
- Increase confidence in predicted performance
- Validate performance and manage risks using on-board tests

Test and Measurement

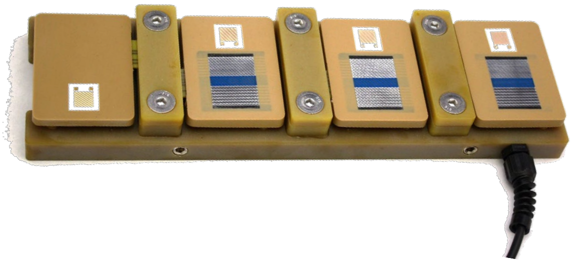
**On-board tests**

**Outdoor tests**

**Laboratory tests**

**Acuity LS**

**Acuity CR**



Implementing preventative **maintenance practices**
- Quantify benefits using on-board measurements

Maintenance

Managing **individual aircraft corrosion** throughout O&S phase
- Optimize inspection intervals
- Detect high corrosion severity conditions
- Track impact of basing and operations

**On-board integration (SAE AIR6970)**

**Acuity LS**

## Corrosion Monitoring Solutions

Test & Measurement: Coating Performance

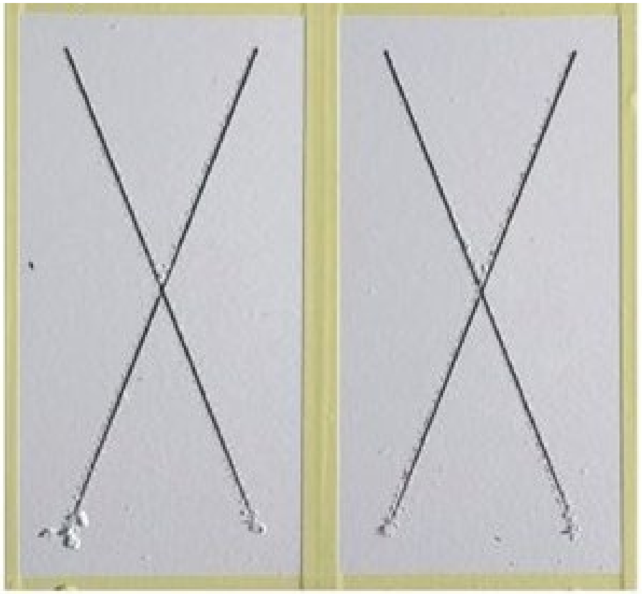
# Performance testing of chromate vs non-chromate primers

| Primer → / Test ↓ | **Chromate SB-Cr-1**<br>MIL-PRF-23377<br>Type I, Class C2<br>Solvent Borne Epoxy | **Chromate SB-Cr-2**<br>MIL-PRF-23377<br>Type I, Class C2<br>Solvent Borne Epoxy | **Non-Chromate SB-NC**<br>MIL-PRF-23377<br>Type I, Class N<br>Solvent Borne Non-Cr | **Non-Chromate WB-NC**<br>MIL-PRF-85582<br>Type I, Class N<br>Water Borne Non-Cr |
| --- | --- | --- | --- | --- |
| **Onboard**<br>• Interior of HH-60G aircraft<br>• 300-day test at severe base location<br>• Two positions; belly and transition | ☑<br>Pretreat: Chromate ($Cr^{+6}$)<br>Topcoat: PU QPD | | ☑<br>Pretreat: Trichrome ($Cr^{+3}$)<br>Topcoat: PU QPD | |
| **Outdoor**<br>• Battelle Florida Research Facility<br>• 130-day test, sheltered<br>• Duplicate measurements | ☑<br>Pretreat: Chromate ($Cr^{+6}$)<br>Topcoat: PU QPD | | ☑<br>Pretreat: Trichrome ($Cr^{+3}$)<br>Topcoat: PU QPD | |
| **Laboratory**<br>• Three laboratory round-robin<br>• GMW-14872 cyclic corrosion test<br>• Triplicate measurements | ☑<br>Pretreat: Trichrome ($Cr^{+3}$)<br>Topcoat: PU QPD | ☑<br>Pretreat: Trichrome ($Cr^{+3}$)<br>Topcoat: PU QPD | ☑<br>Pretreat: Trichrome ($Cr^{+3}$)<br>Topcoat: PU QPD | ☑<br>Pretreat: Trichrome ($Cr^{+3}$)<br>Topcoat: Pu QPD |

# Continuous, quantitative sensor measurements

**Legacy Methods**

Visual rating of scribe creep and corrosion products

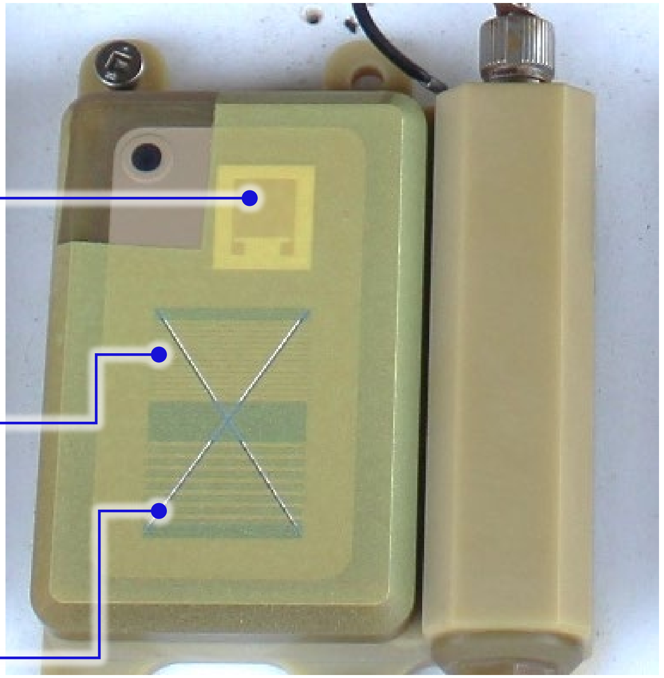


**Acuity Measurements**

BARRIER
Coating conductance
Rate (μS)
Cumulative (C/V)

CORROSION
Free corrosion rate
Current (μA)
Cumulative (C)

GALVANIC CORROSION
Galvanic corrosion rate
Current (μA)
Cumulative (C)



# Acuity LS and CR systems for coatings performance

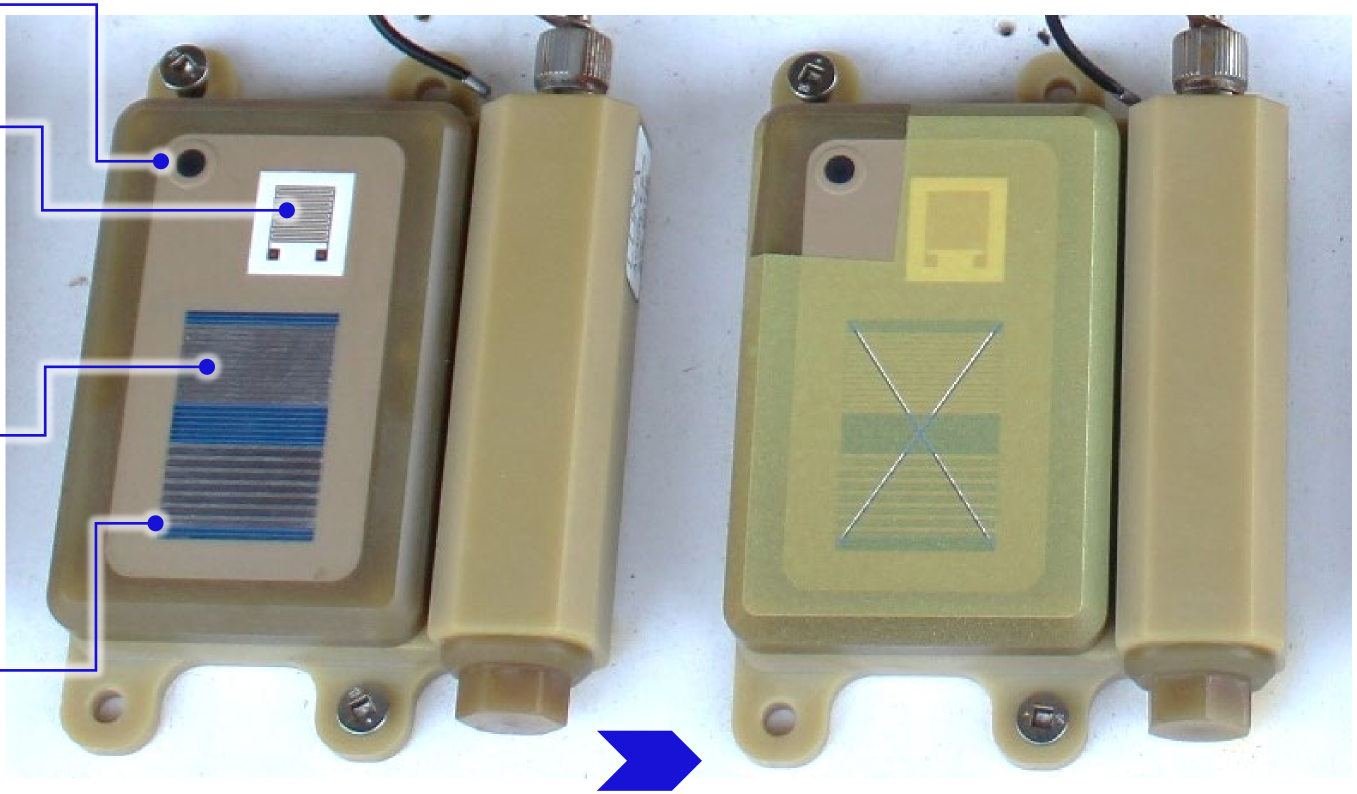
**Acuity LS**

TEMPERATURE &
RELATIVE HUMIDITY

BARRIER
Coating conductance
Rate (µS)
Cumulative (C/V)

CORROSION
Free corrosion rate
Current (µA)
Cumulative (C)

GALVANIC CORROSION
Galvanic corrosion rate
Current (µA)
Cumulative (C)



Pretreat, paint, and process sensor panel per standard techniques

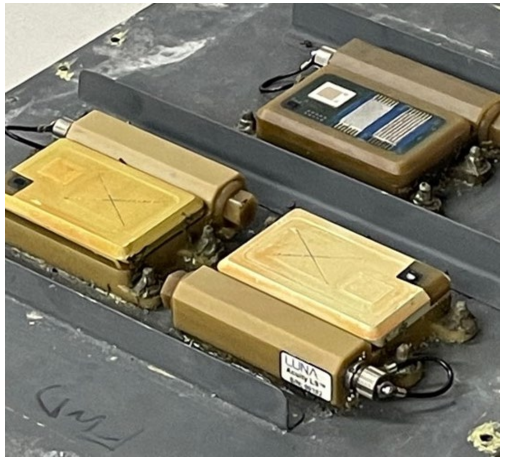
# On-board Coating Performance

**Non-chromate SB-NC**

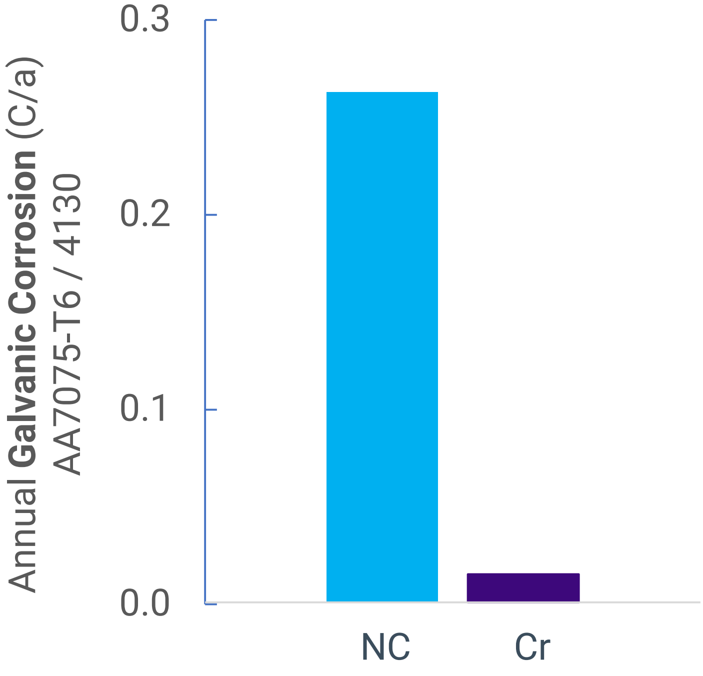
| | |
|---|---|
| Primer: | MIL-PRF-23377K Type 1 Class N<br>Non-chromate solvent borne epoxy |
| Pretreatment: | MIL-DTL-5541<br>Trichrome conversion coating |

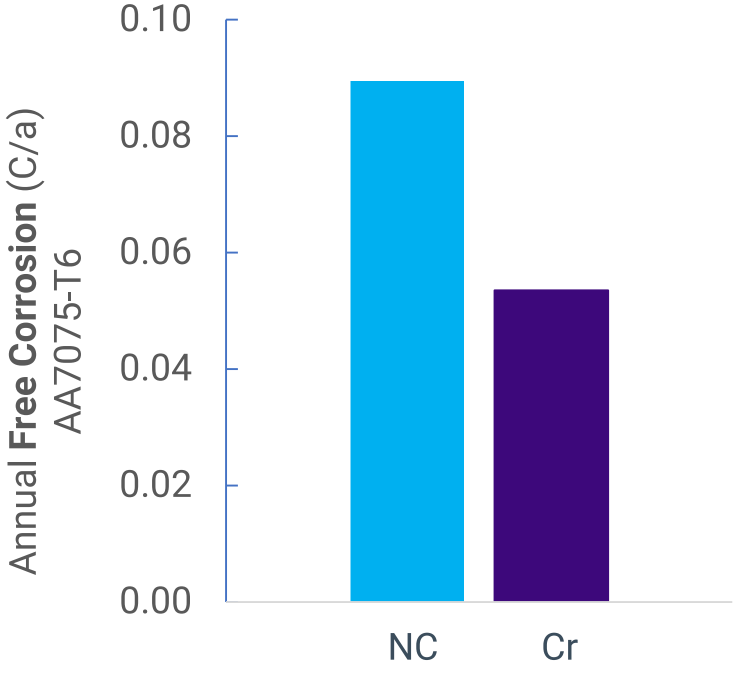
**Chromate SB-Cr-1**

| | |
|---|---|
| Primer: | MIL-PRF-23377 Type 1, Class 2<br>Solvent-borne epoxy |
| Pretreatment: | MIL-DTL-5541 Class1A<br>Chromate conversion coating |




300-day test on HH-60G
Belly and transition installations




Largest difference in non-chromate and chromate coating performance is associated with galvanic corrosion protection

# Outdoor Coating Performance

**Non-chromate SB-NC**

Primer: MIL-PRF-23377K Type 1 Class N
Non-chromate solvent borne epoxy

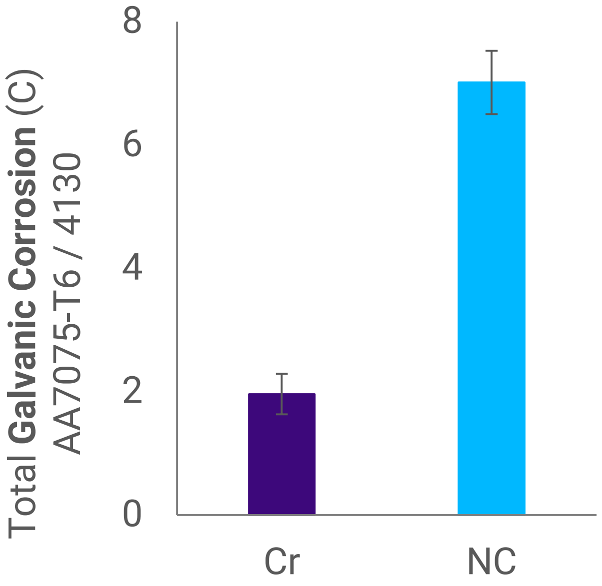
Pretreatment: MIL-DTL-5541
Trichrome conversion coating

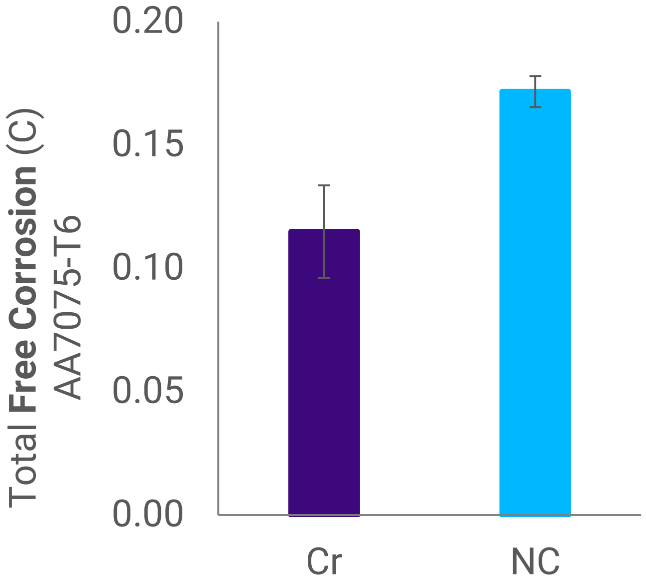
**Chromate SB-Cr-1**

Primer: MIL-PRF-23377 Type 1, Class 2
Solvent-borne epoxy

Pretreatment: MIL-DTL-5541 Class1A
Chromate conversion coating

130-day test at
Battelle Florida Materials
Research Facility



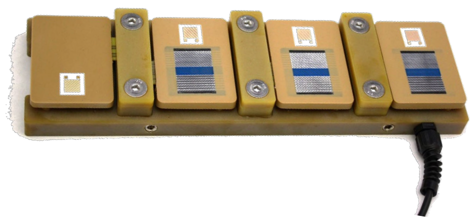

Largest difference in non-chromate and chromate coating performance is associated with galvanic corrosion protection

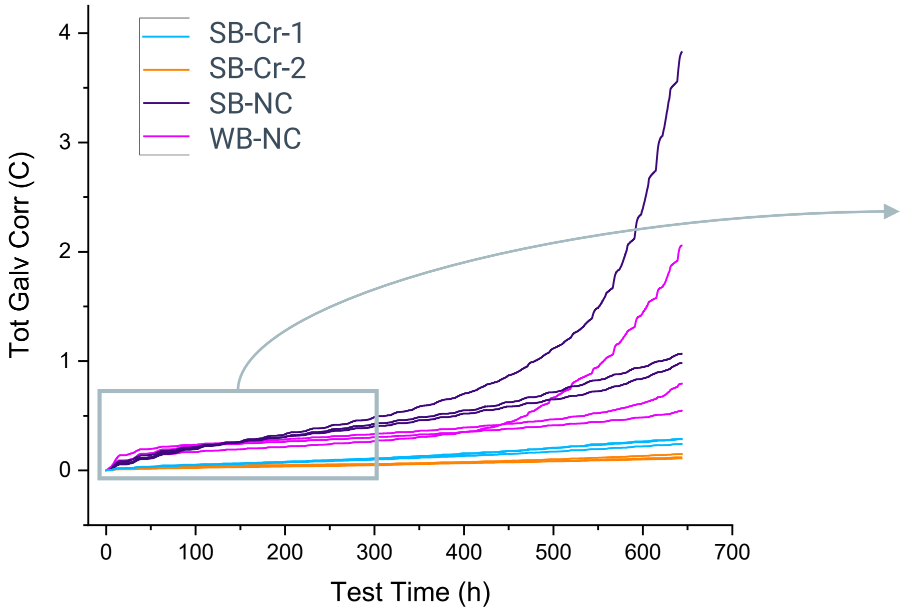
# Laboratory Coating Performance: Total galvanic corrosion

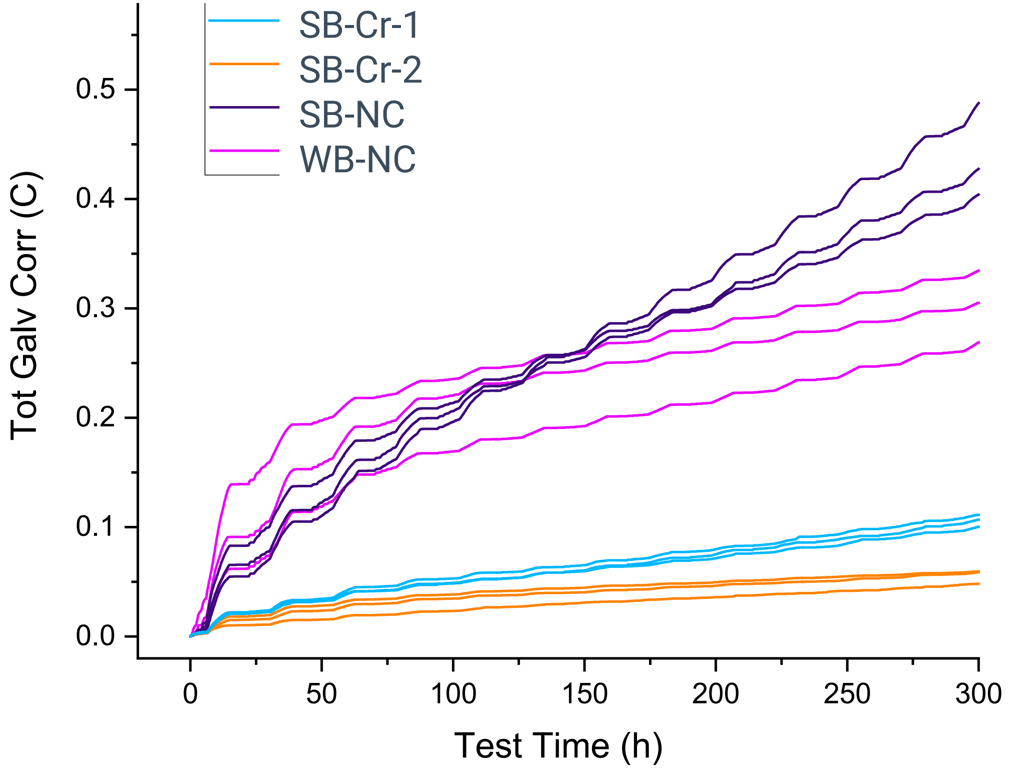
**Measurement of galvanic corrosion rate for approximately 25 cycles of GMW-14872 cyclic corrosion test with triplicate measurements for each coating system**

- Change in protective properties of non-chromate coatings apparent after 400 hours
- Galvanic corrosion performance separation of coatings apparent within 100 hours

**Acuity CR**

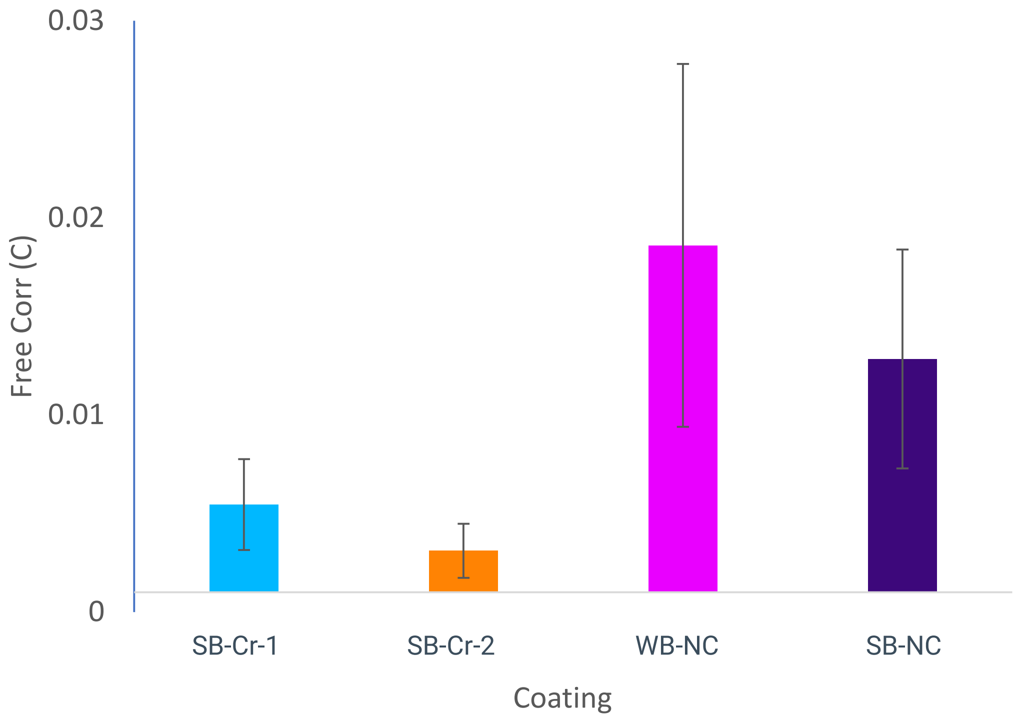


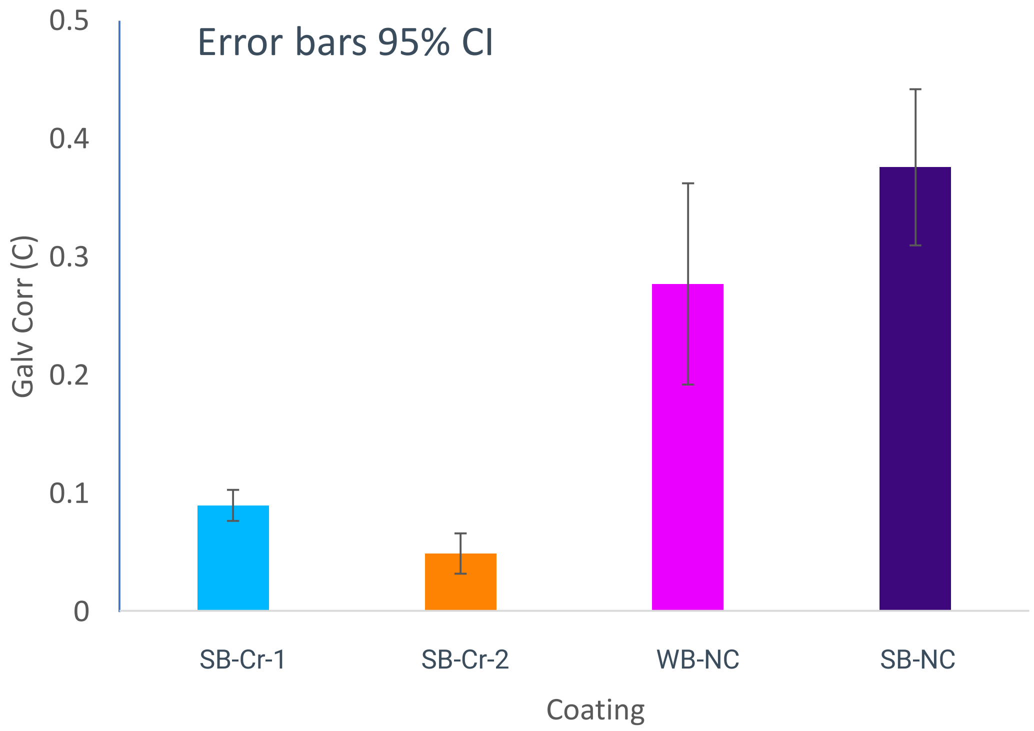


# Free and galvanic corrosion at 250 Hours: Lab-A

- Significant free corrosion and galvanic corrosion separation in non-chromate and chromate coating performance
- Significant separation in galvanic corrosion between the two qualified chromate coatings



# Industry adoption

Develop, demonstrate, and standardize advanced measurement methods for assessing coating performance

- ✓ Produce electrochemical sensors and data collection system for rapid, accurate characterization of coating performance
- ✓ Demonstrate capability in interlaboratory tests, outdoor exposures, and on-board aircraft
- ✓ Publish U.S. national standard test method

- ❑ Establish coating performance requirements based on metrics defined in the standard test method
- ❑ Adopt measurements and requirements within aerospace performance specifications

AMPP TM21449-2021, Continuous Measurements for Determination of Aerospace Coating Protective Properties

WIP 2012-01-17

**Atmospheric Corrosion Monitoring Informational Report**

AIR6970

Standards About us News Taking part Store EN ☰ MENU

ICS › 77 › 77.060

**ISO 22858:2020**

**Corrosion of metals and alloys — Electrochemical measurements — Test method for monitoring atmospheric corrosion**

Corrosion Monitoring Solutions

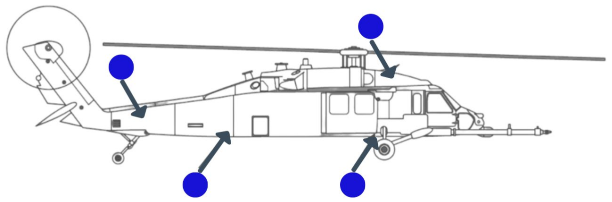
Maintenance: On-board Integration

# U.S. Navy Value Proposition for CH-53K Fleet of 200

Navy's ROI analysis for integrating Luna Labs monitoring devices with vehicle health management system (IVHMS)

- **250,000 reduced maintenance man hours** during service life of fleet
- For 60% of the fleet, **double wash cycles** from 14 to 28 days
- For 60% of the fleet, **extend inspection cycle time** by 10%

Tracking corrosivity and environment spectra within an airframe

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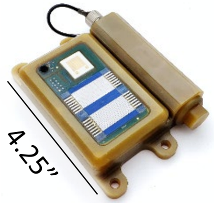
# Netherlands Royal Air Force Recognizes Savings when Deferring Inspections for NH-90s

- Netherlands Aerospace Research Laboratory (NLR) is using Luna Labs corrosion monitoring systems to defer corrosion inspections

- **$200,000+ savings by deferring a single corrosion inspection** until a scheduled maintenance inspection

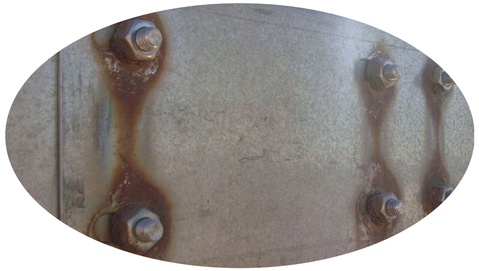
- Increased availability



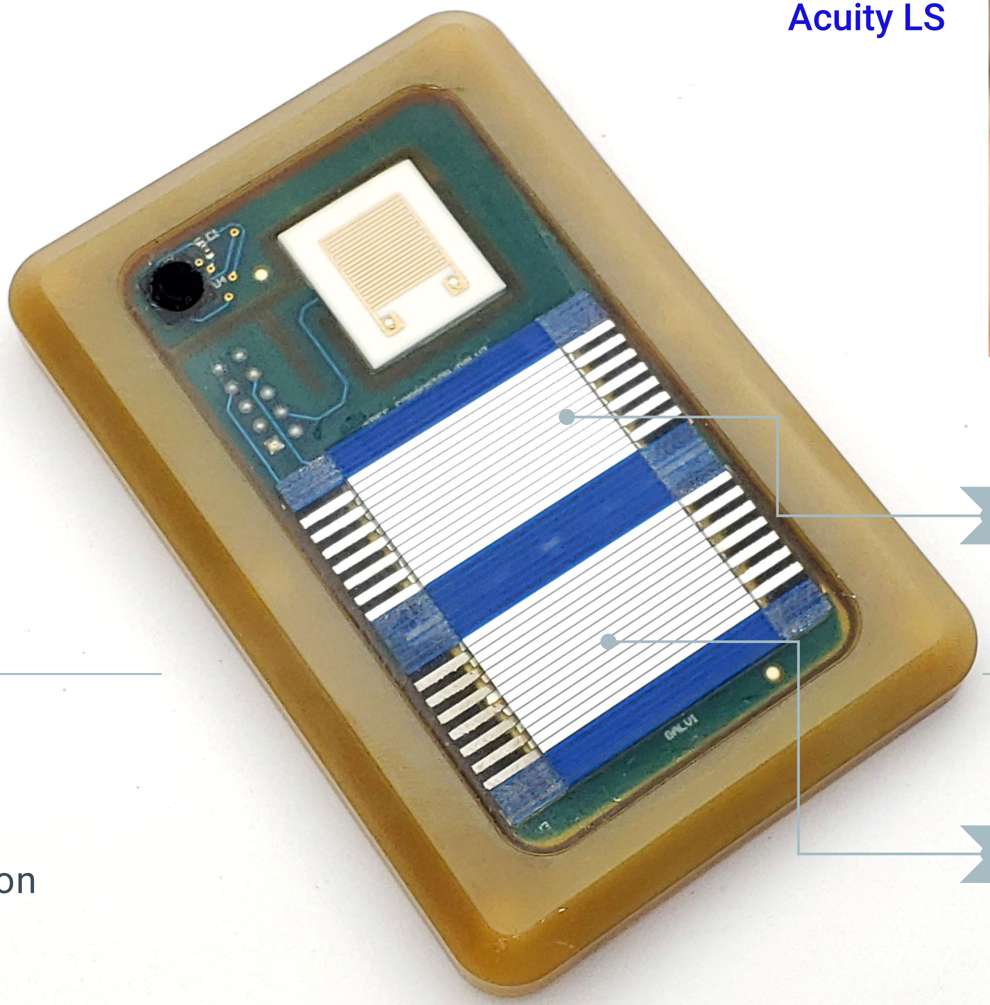

Luna Labs sensor devices

# Continuous, Quantitative Measure of Corrosivity

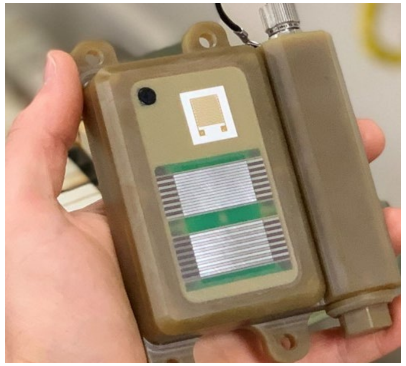

Single metal
free corrosion



Mixed-material
galvanic corrosion



Acuity LS

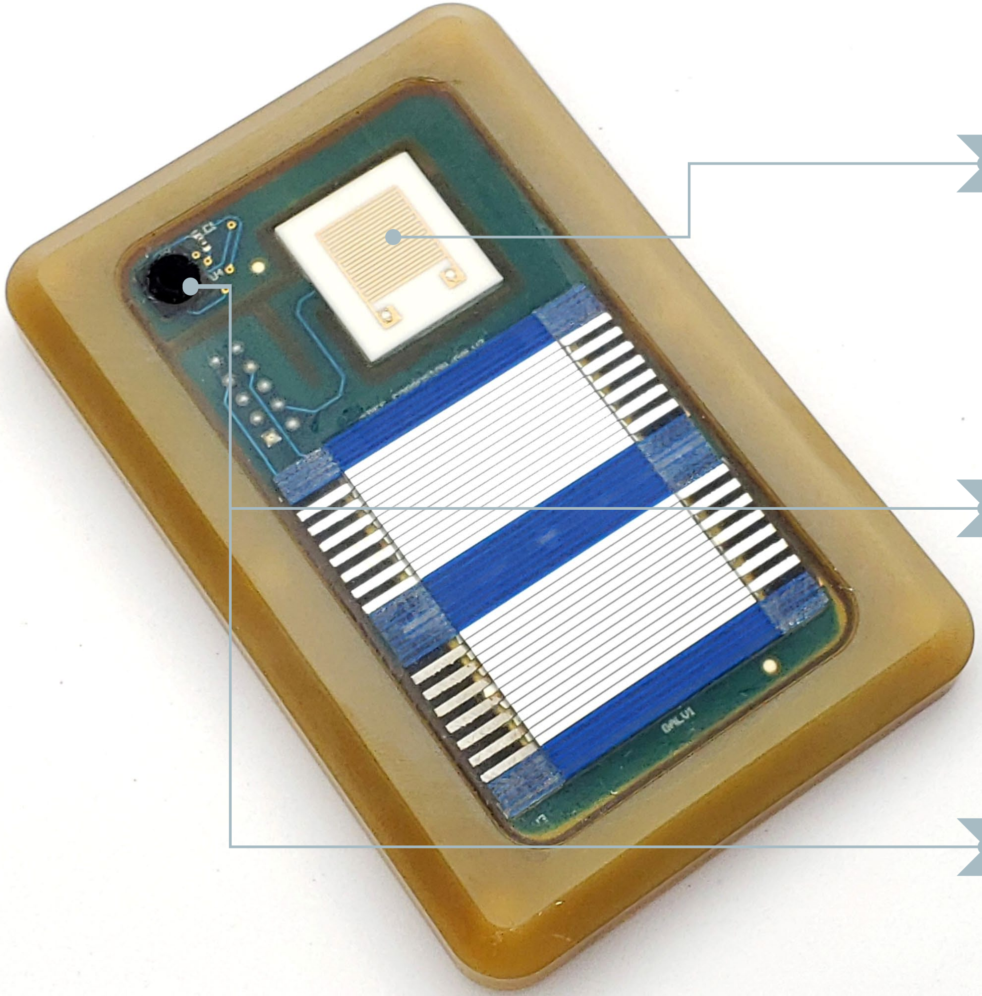


**FREE CORROSION**
Current (μA)
Cumulative (C)

**GALVANIC CORROSION**
Current (μA)
Cumulative (C)

# Critical Parameters of Environmental Spectra

Salt loading and
time-of-wetness



**CONDUCTANCE**
(RH & salt deposition)
Rate (μS) & Cumulative (C/V)

**RELATIVE HUMIDITY**

**AIR TEMPERATURE**

# Development History

Independent projects using Luna Labs technology are being led by AFRL, AFLCMC, NRL, NAWCAD, Netherlands Aerospace Laboratories, Polish Air Force Institute of Technology, Airbus, and Leonardo

SAE INTERNATIONAL

WIP 2012-01-17
**Atmospheric Corrosion Monitoring Informational Report**
AIR6970

**SAE HM-1 Integrated Vehicle Health Management Committee**
Environment Spectra and Corrosivity Monitoring Using Electrochemical and Electrical Resistance Sensors

AMPP™ AD HOC I-SC 07 Environment Spectra and Severity Classification

**2007** Development Initiated

**2014** begin US DoD demonstrations

- UH-1N
- HH-60G
- B-52
- LDH-1
- F-15

**2015** Protype product released

**2016** Netherlands using first gen product to manage NH90

**2017** CH-53K Projects Started

**2018** USAF wash interval study

- C-5
- HH-60G
- C-130
- B-1
- Ten bases worldwide

**2019** HH-60W Projects Started

**2019** next-gen product flown by Polish Air Force

**2020** C130 Projects Started

**2020** Acuity LS released

- CH-53K
- HH-60W/G
- F-22 clear water rinse study
- Airbus
- Boeing

**2021** prototype of information dashboard for fleet management

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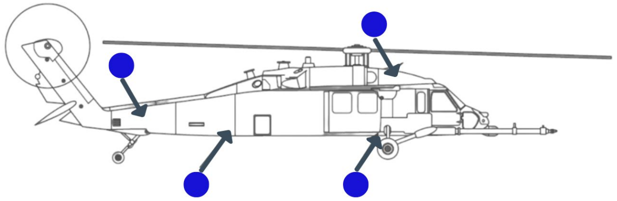
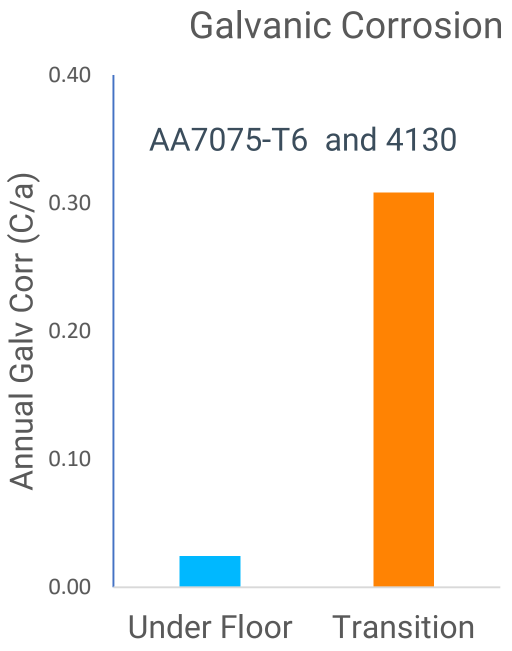
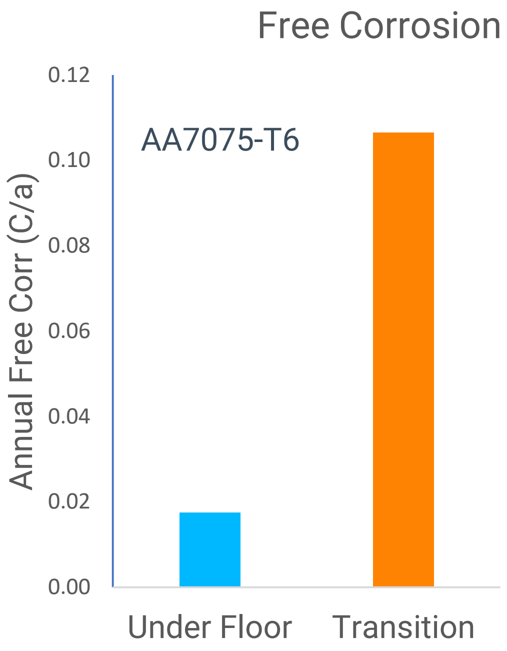
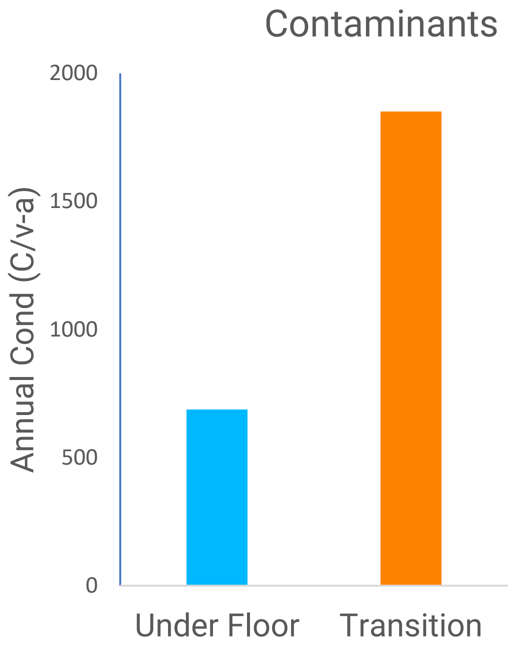
# Helicopter Transition and Under-floor Severity

- Annual rates for contaminants, galvanic corrosion, and free corrosion produce consistent results
- For these aircraft, the severity within the transition is higher than for the under-floor area





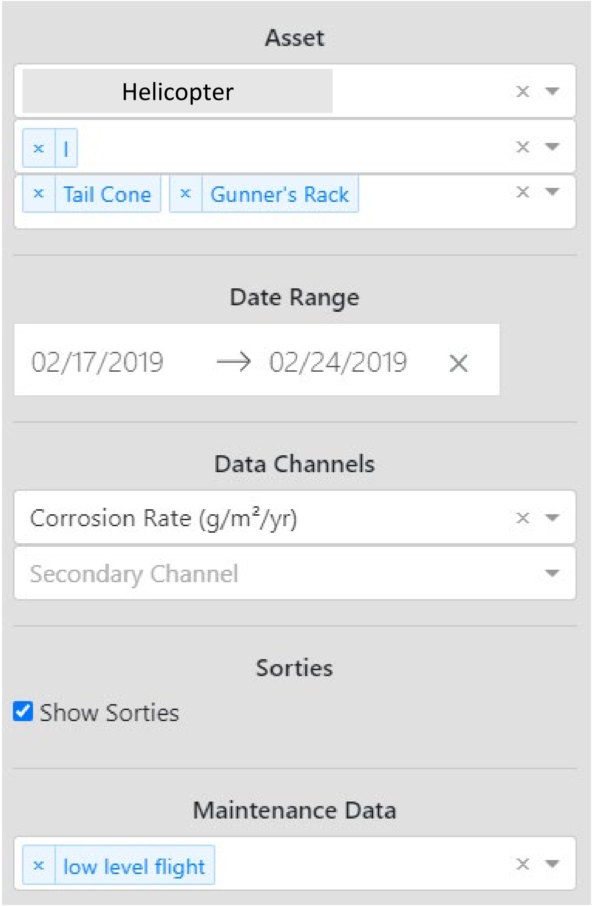



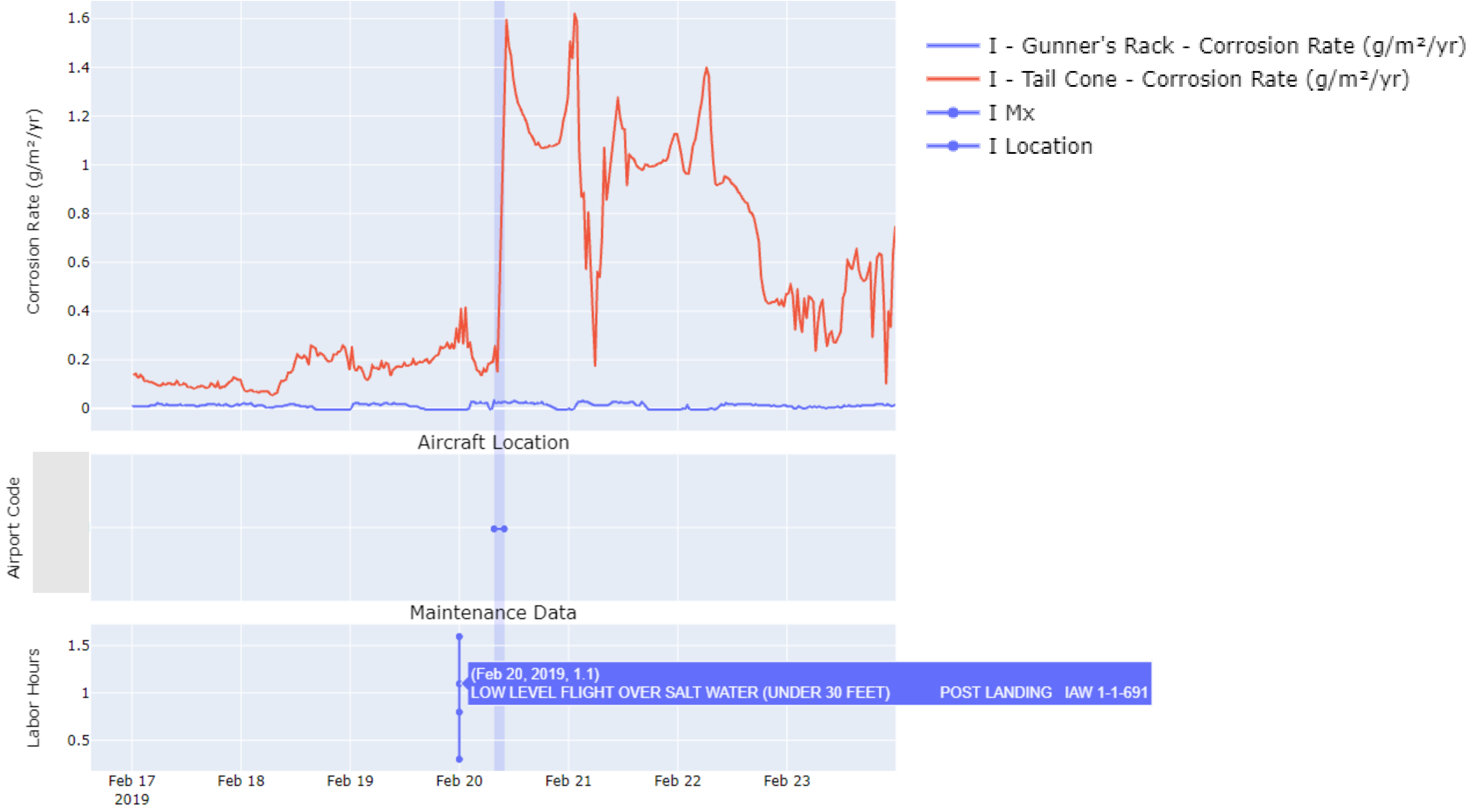




Average annual rates determined from six aircraft

# Influence of Operations

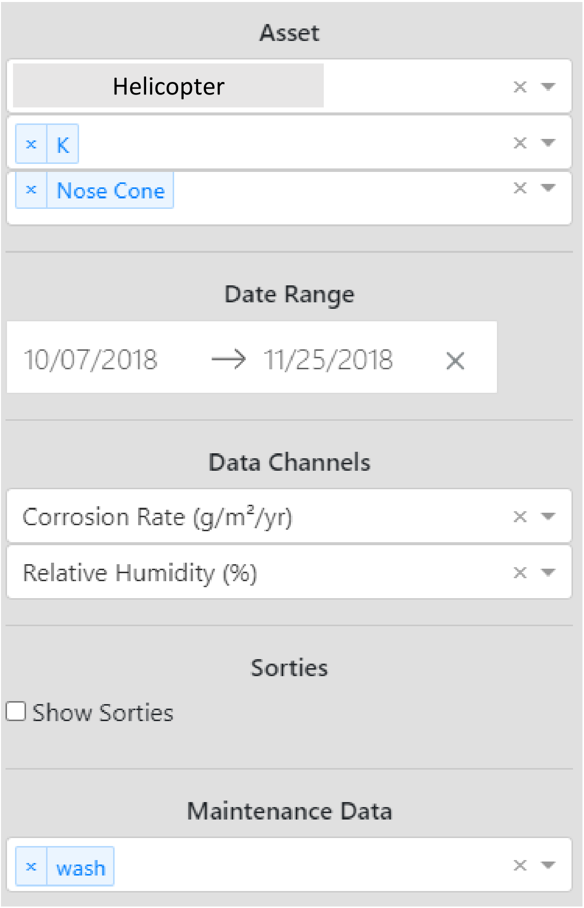
Corrosivity response in helicopter tail cone associated with low level flight over salt water

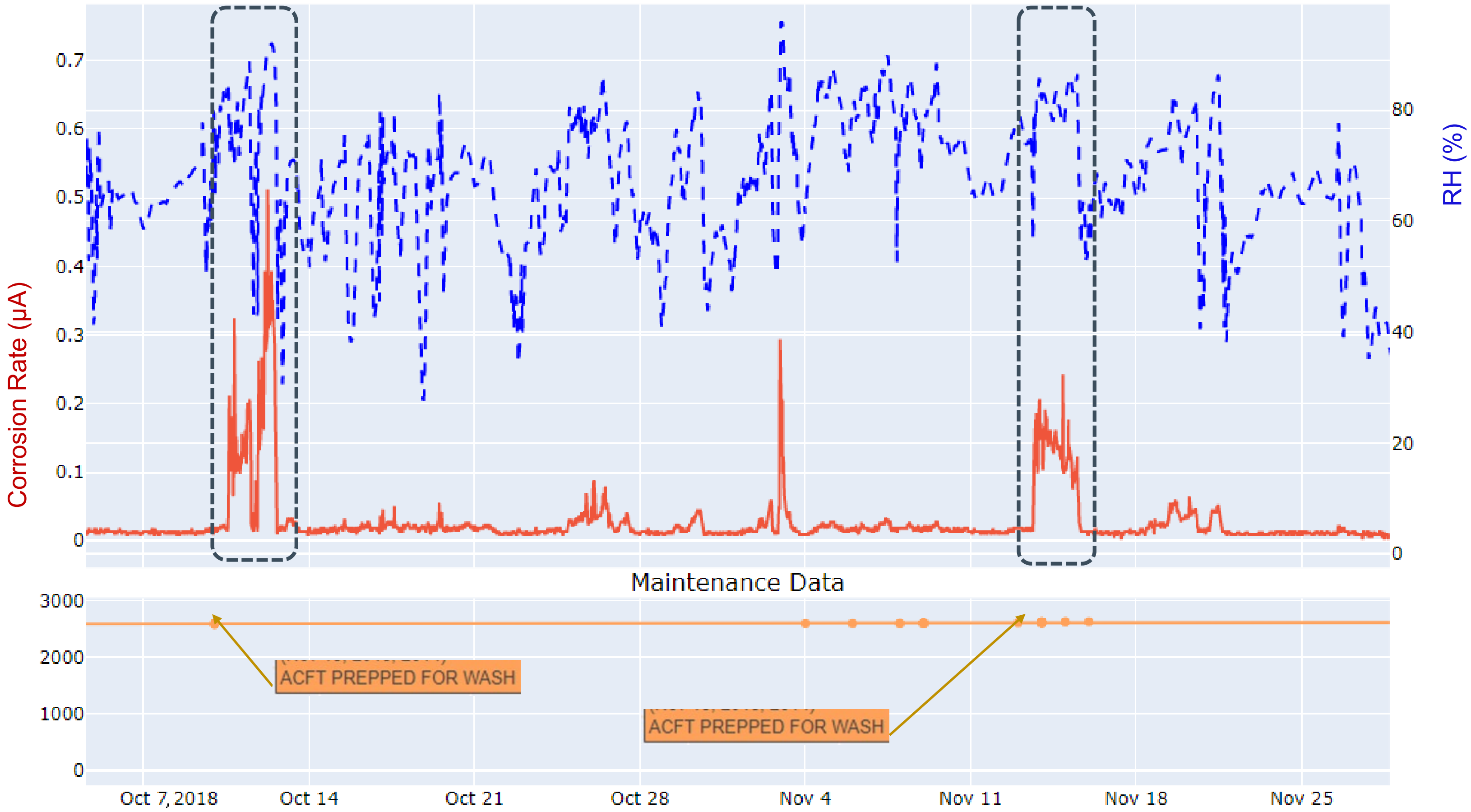


# Influence of Maintenance

Corrosion event in nose cone due to high humidity from helicopter wash



# Aircraft Corrosion Health Monitoring – Moving Forward

- Leverage partnerships with US DoD and international organizations to prioritize and defer inspections through tracking of individual aircraft corrosivity and environment spectra

- Connect on-aircraft corrosivity and environment spectra with maintenance/operations data to optimize the use of aircraft corrosion protection and control technologies

- Identify how Luna Labs may support initiatives across DoD aviation to increase aircraft availability and reduce maintenance costs through condition-based corrosion maintenance

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Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the United States Air Force.

Thank You

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# Acuity LS Parts

### Base

- Surface temp sensor
- RS-485 comm port
- User-replaceable battery

### Lid Sensor Panel

- Corrosion sensors
- Contaminants sensor
- RH & Temp sensor

SAFT LS17500 A 3.6V
3600mAh Lithium Battery

- Device weight – 0.7 lb (317 g)
- Dimensions 1.05” x 4.8” x 3.5” (2.67 cm x 12.19 cm x 8.89 cm)

Engineering alloys selected by customer alloy combinations:

| Free Corrosion Sensor | Galvanic Corrosion Sensor |
|---|---|
| AA6xxx | AA6xxx/1008 |
| AA6xxx | AA6xxx/SS316 |
| AA6061-T6 | AA7075-T6/Ti6-4 |
| 1008 | AA6061-T6/1008 |
| 1008 | EN988 Zinc/1008 |
| AA7075-T6 | AA7075-T6/SS316 |
| AA7075-T6 | AA7075-T6/4130 |
| AA7075-T6 | AA7075-T6/A286 |
| AA7075-T6 | AA7075-T6/Ti6-4 |
| AA2024-T3 | AA7075-T6/SS316 |
| AA2024-T3 | AA2024-T3/4130 |
| AA2024-T3 | AA2024-T3/A286 |
| AA2024-T3 | AA2024-T3/Ti6-4 |

| Dual Galvanic Sensors | |
|---|---|
| AA6061-T6/CFRP | AA6061-T6/CFRP |
| AA7075-T6/Ti-6Al-4V | AA7075-T6/CFRP |

# AMPP TM21449-2021 Aerospace Coating Protective Properties

**Standard describing three Test Methods for comparative coating performance testing**

- Barrier Properties of a Coating
- Protective Corrosion Properties of a Coating at a Defect
    - Galvanic corrosion
    - Free (self) corrosion
- Protective Properties of a Coating for Environmental Cracking Resistance

## Continuous Measurements for Determination of Aerospace Coating Protective Properties







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