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

Use of Environment and Corrosivity Monitoring to Characterize Base and Airframe Severity

Fritz Friedersdorf and Liam Agnew, Luna Labs, USA

https://acuitycorrosion.com/

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Outline and Acknowledgement

- Issue
- Objectives and Approach
- Project Description
- Results
  - Environment
  - Salt deposition
  - Corrosion
- Severity Classification for Aircraft Maintenance
- Summary

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Issue

- **Corrosion accounts for 24% of all US DoD aviation and missile maintenance costs (LMI, 2018)**
- **Currently, 60% - 70% of DoD aviation enterprise maintenance is corrective (Herron, 2022)**
  - Corrective maintenance is the most disruptive to cost, schedule, and availability
- **Preventative maintenance is prescribed by static instructions (TO 1-1-691, NAVAIR 01-1A-509-2) that do not account for dynamic climatic conditions and severity**
  - Severity classification (mild, moderate, and severe)
  - Sea-basing and proximity to a coastline

Issue

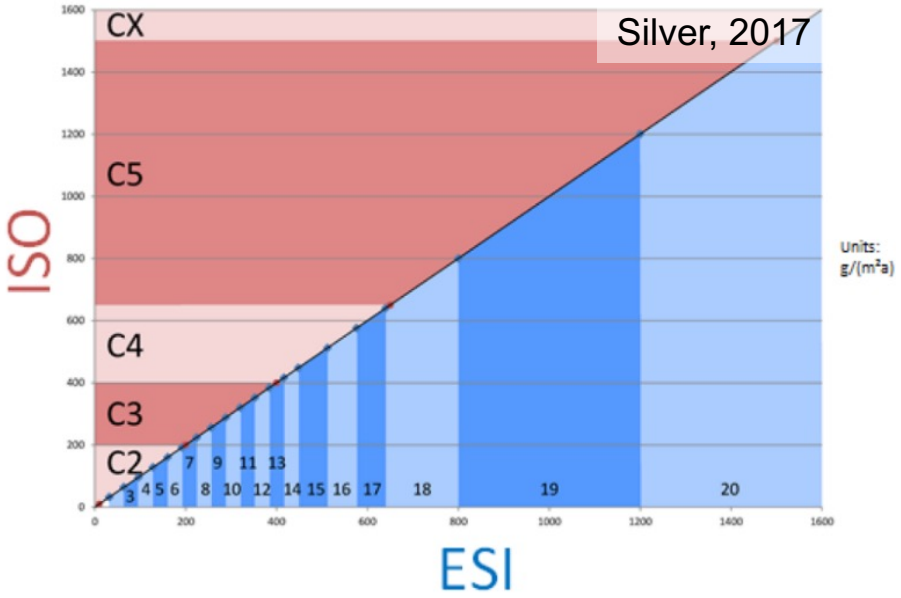
Issues with determining service environment severity are:

1. **Lack of commonality in classification systems**
2. **Antiquated classifications established anywhere from 20 – 50 years ago**
3. **Classifications that do not use aerospace materials nor galvanic couples**
4. **No specific method for setting or validating classifications**
5. **No accepted method to assess or track severity**

TO 1-1-691: mild, moderate, severe

DoD ICCET and ISO 9223: C1 – CX for steel, zinc, copper, aluminum mass loss

DoE ESI: 1 – 20 for steel mass loss



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Objective and Approach

- **Increase aircraft capability and maintenance efficiency**
  - Inform preventative maintenance by assessing and tracking corrosion severity

- **Characterize environmental factors that determine corrosion severity**
- **Measure corrosion severity using monitoring devices that are appropriate for assessing base locations and individual aircraft**
- **Recommend classification methods for severity assessment relevant to aircraft**

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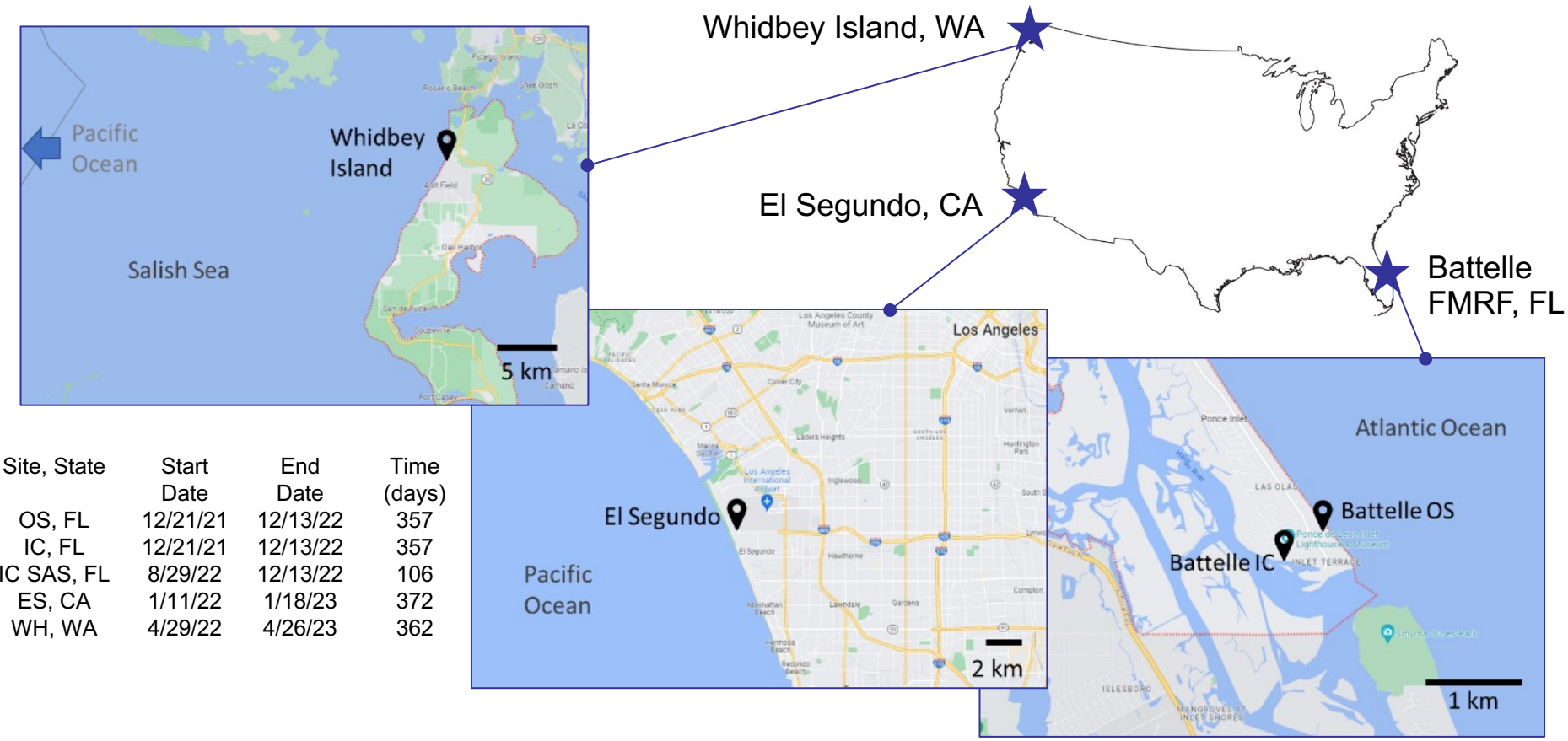
Locations

Environment and corrosion measurements have been made to quantify severity at multiple locations



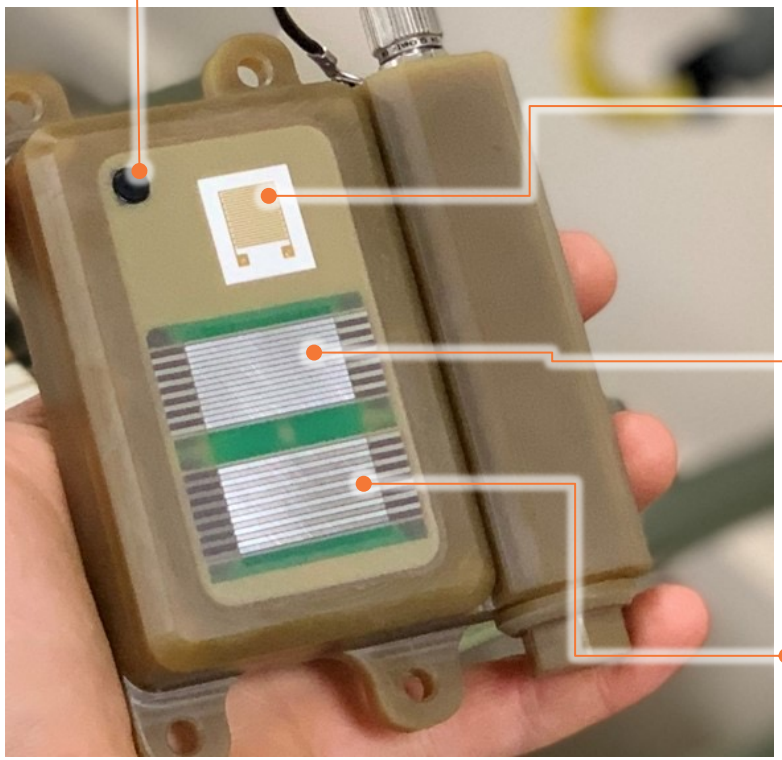
Site, State	Start Date	End Date	Time (days)
OS, FL	12/21/21	12/13/22	357
IC, FL	12/21/21	12/13/22	357
IC SAS, FL	8/29/22	12/13/22	106
ES, CA	1/11/22	1/18/23	372
WH, WA	4/29/22	4/26/23	362

Test Conditions

- **Environment and corrosion monitoring devices were boldly exposed**
  - Tested within open back simulated aircraft structures at Battelle intracoastal (IC) site

Facing main body of water at 30 degrees from horizontal

Measurements

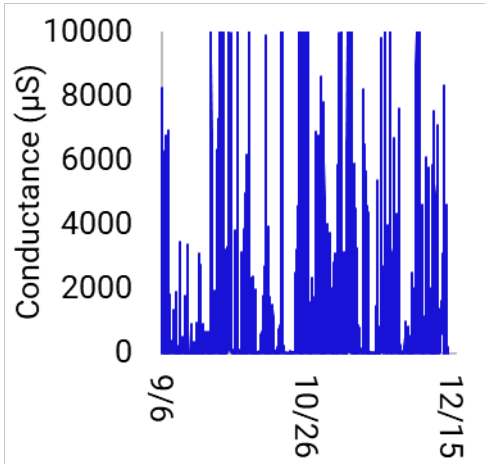


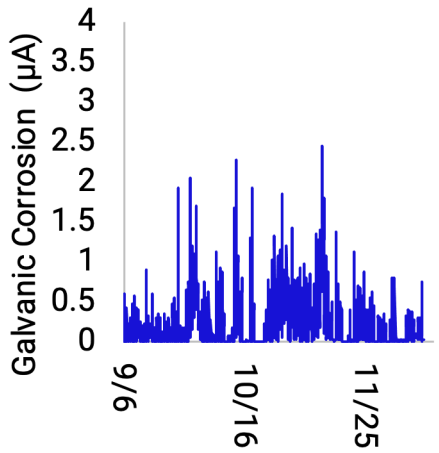
Air temperature & relative humidity

Conductance
- Gold
- 20 mV peak-to-peak
- 10 Hz and 25 kHz
- Conductance (μS)

Free corrosion rate
- Single engineering alloy
- Linear polarization resistance
- 20 mV peak-to-peak, 0.5 Hz
- Current (μA)

Galvanic corrosion rate
- Two dissimilar materials
- Zero resistance ammeter
- Current (μA)





Measurements and Materials

- **Environment and corrosion measurements were obtained from site monitoring devices and weather station data**
- **Corrosion**
  - Galvanic corrosion: Ti-6Al-4V / AA7075-T6
    A286 / AA7075-T6
    CFRP / AA7075-T6
  - Free corrosion: AA7075-T6

- **Weather station: National Oceanic and Atmospheric Administration (NOAA)**
  - National Centers for Environmental Information (temp, RH, wind speed, wind direction)
  - National Data Buoy Center (wave height)
  - Wet candle measurements at the Battelle intracoastal and ocean sites

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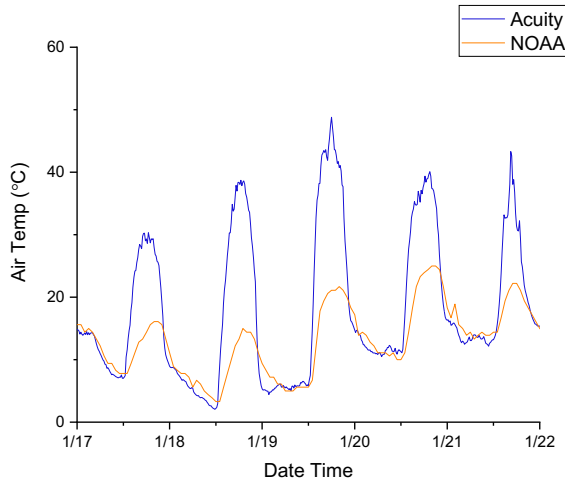
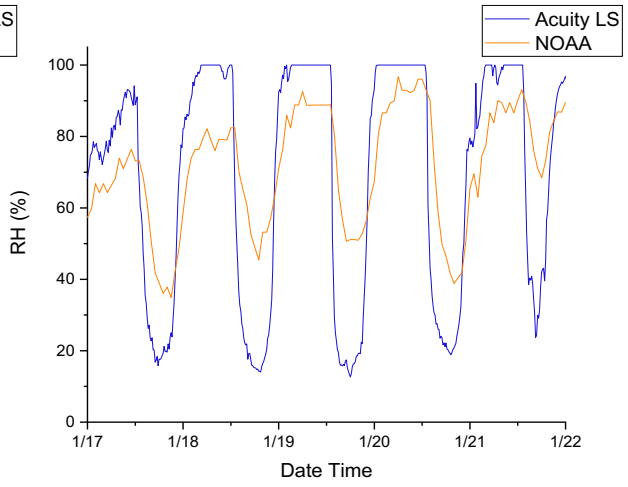
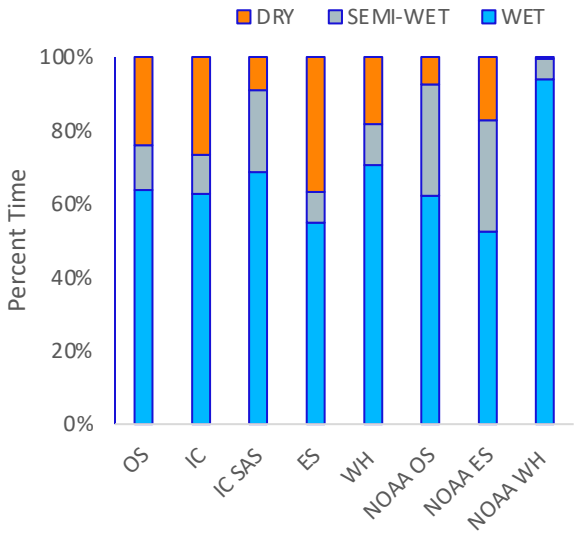
Temperature and Relative Humidity

- Solar radiation during the day dries off boldly exposed surfaces
- Black body cooling over night produces wet conditions
- Sheltering reduces dry time

Dry RH < 50%
Wet RH > 70%
T > -20 ˚C

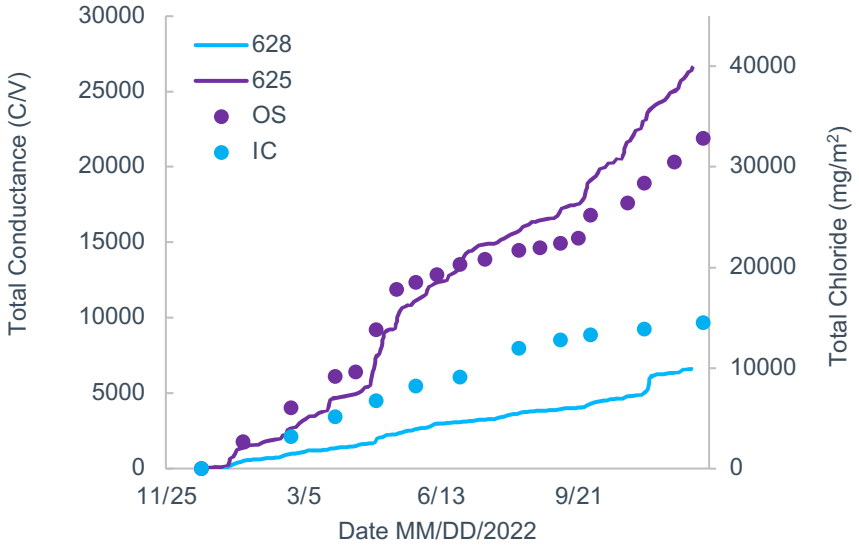






Salt Deposition

- **Conductance and wet candle measurements of chloride deposition have similar trends**
- **The sheltered condition has the highest annual conductance**
- **The least severe location (IC) becomes the most severe when sheltered (IC SAS)**



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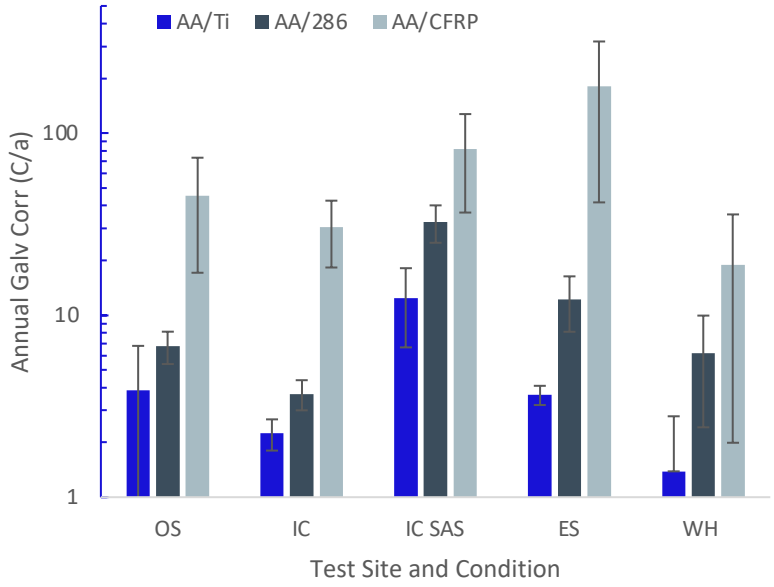
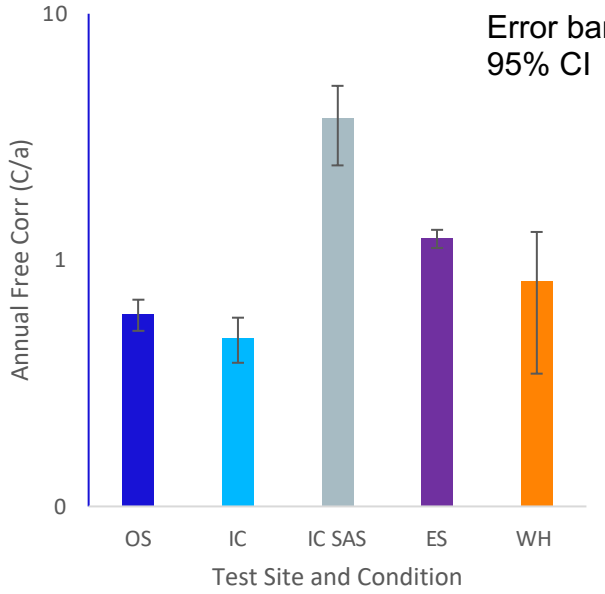
Corrosion

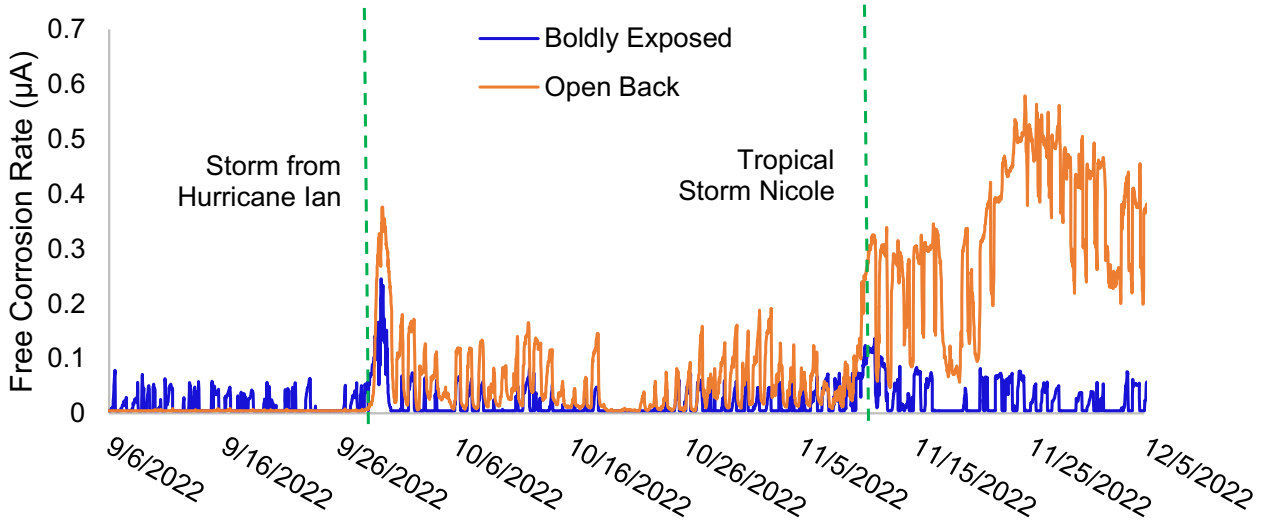
- **Rank order of galvanic corrosion was the same at each test site**
  CFRP > A286 > Ti 6-4 versus AA7075-T6
- **Test site rank order severity was similar based on material annual corrosion**
  IC SAS > El Segundo > Battelle Ocean Site > Whidbey Island > Battelle Intracoastal
  - ➢ Rank order severity agreed with conductance results





Summary of Environment and Corrosion Results

- **The site and condition with the least rain and condensation rinsing produced the most severe conditions**
  - The SAS box was the most severe condition even though this was the least severe site for boldly exposed devices
- **El Segundo was the driest site, but also had high severity due to salt accumulation**



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Severity Classification

- **Conductance and corrosion rate of aerospace alloys may be used to determine severity categories**
- **ISO 9223 C1 – CX Categories**
  - Assumes Battelle ocean site corresponds to 20% of the C5 range for aluminum
  - Corrosion sensors can be selected for optimal resolution and longevity

ISO 9223 Category	ISO 9223	Annual Corrosion (r)				Daily Cond (s)
	Aluminum ($g/(m^2\text{-}a)$)	AA7075/Ti-6-4 (C/a)	AA7075/A286 (C/a)	AA7075/CFRP (C/a)	AA7075 (C/a)	Gold IDE (C/(V·d))
C1	negligible	$r \le 0.02$	$r \le 0.03$	$r \le 0.2$	$r \le 0.03$	$s \le 0.7$
C2	$r \le 0.6$	$0.02\ r \le 0.4$	$0.03 < r \le 0.7$	$0.2 < r \le 3.5$	$0.03\ r \le 0.06$	$0.7 < s \le 6.6$
C3	$0.6 < r \le 2$	$0.4 < r \le 1.3$	$0.7 < r \le 2.2$	$3.5 < r \le 11.7$	$0.06 < r \le 0.2$	$6.6 < s \le 22.1$
C4	$2 < r \le 5$	$1.3 < r \le 3.2$	$2.2 < r \le 5.6$	$11.7 < r \le 29.2$	$0.2 < r \le 0.5$	$22.1 < s \le 55.3$
C5	$5 < r \le 10$	$3.2 < r \le 6.4$	$5.6 < r \le 11.2$	$29.2 < r \le 58.4$	$0.5 < r \le 1.01$	$55.3 < s \le 110.6$
CX	$R > 10$	$6.4 < r$	$11.2 < r$	$58.4 < r$	$1.01 < r$	$110.6 < s$

Severity Classification

- **The ISO corrosivity category for each site was determined from corrosion and conductance data**
- **Severity can be determined using monitoring devices and material couples that are relevant to aerospace structures**

Color key

C1	C2	C3	C4	C5	CX

Site	AA7075/Ti6-4	AA7075/286	AA7075/CFRP	AA7075	Cond	Mode
Battelle OS	3.87	6.75	45.21	0.60	66.38	C5
Battelle IC	2.24	3.70	30.42	0.48	15.28	C4
Battelle IC SAS	12.39	32.55	81.97	3.76	356.29	CX
El Segundo	3.65	12.22	180.31	1.22	124.28	CX
Whidbey Island	1.39	6.18	18.88	0.82	52.43	C4

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Summary

- **Conductance and corrosion measurements may be appropriate for assessing and surveying site severity and aircraft tracking**
  - Track corrosion severity by location and individual aircraft to optimize wash schedules and corrosion inspection and maintenance
- **These measurements may allow a unified approach for classification of severity**
  - TO 1-1-691, DoD ICCET, ISO 9223, DoD ESI, NAVAIR 01-1A-509-2
- **Small changes in distance from the coast and sheltering can have significant influence on corrosion severity**

Thank You

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Fritz Friedersdorf

Fritz.friedersdorf@lunalabs.us

+1 434 220 0148

Backup Slide – Environment Spectra Data

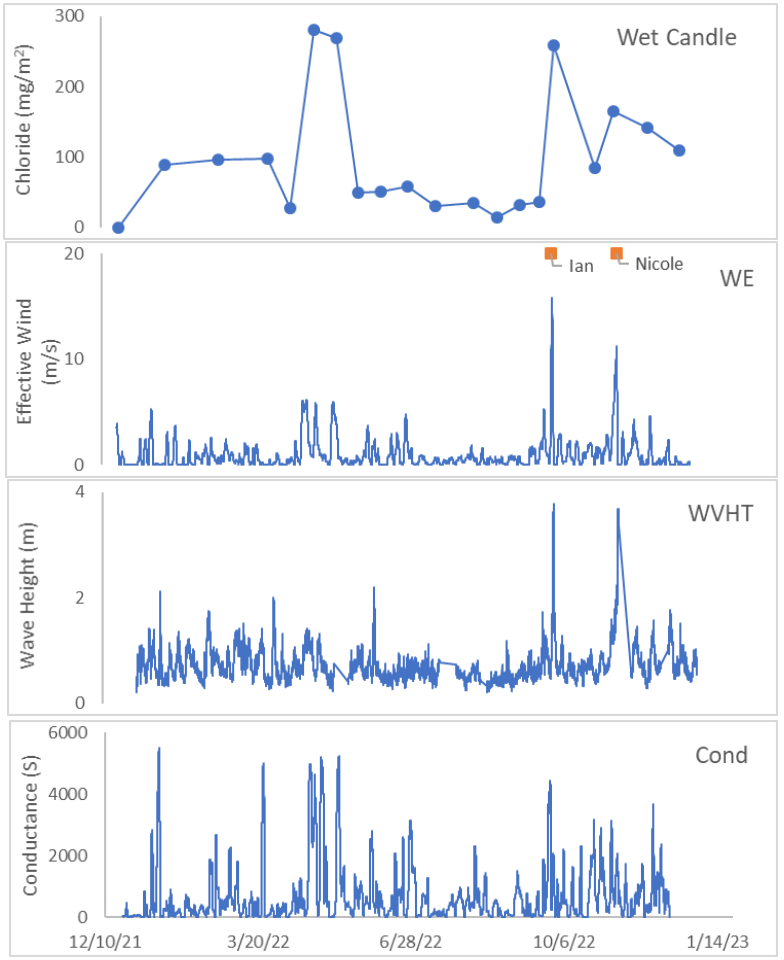
	Severity Monitoring Device					NOAA		
Site	**OS**	**IC**	**IC SAS**	**ES**	**WH**	**OS**	**ES**	**WH**
Air Temp (°C)	26.0	27.0	24.7	23.8	12.5	22.4	17.7	9.4
RH (%)	75.2	73.7	77.6	65.5	79.7	74.8	66.7	89.9
ToW ISO (%)	54.4	55.2	53.5	49.6	58.3	45.7	29.4	84.9
TW AC (%)	62.7	62.7	68.6	55.0	70.5	62.2	52.3	93.9
TSW AC (%)	12.0	10.7	22.3	8.3	11.2	30.3	30.3	5.6
TD AC (%)	23.7	26.7	9.1	36.8	18.3	7.5	17.3	0.5
Cond (C/V/d)	66.38	15.28	356.29	124.28	52.43	-	-	-
WE (km/d)	-	-	-	-	-	86.61	164.04	146.34
WVHT (m)	-	-	-	-	-	0.71	1.00	0.40
S_d (mg/(m²·d))*	95.1	42.1	-	-	-	-	-	-
Rain (mm/a)**						1050	345	515

* Wet candle

** Climate-Data.org

Backup Slide

- **Measurements related to chloride deposition – wet candle, effective wind, wave height, and conductance**
  - Dates for hurricanes Ian and Nicole are noted
- **Qualitatively, wet candle, wave height, and effective wind have similar time dependent trends**
- **Salt removal by condensation and precipitation is also expected to be important for determining the amount of salt on a surface at any given time**



Backup Slide

- **On-shore winds are generally greatest midday; while, RH, conductance, and corrosion rates are highest overnight and early in the morning**
  - For a shore-based aircraft located outside, salt deposition would be expected during the day with corrosion occurring overnight
  - For sea-based aviation, wind speed, independent of direction, and wave height may be determining factors for salt deposition