Synergistic Prognostic Modeling of Atmospheric Corrosion

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• Travis Lucero and Richard Holmes – Hill AFB
Corrosion costs to USAF have been estimated to be $5.0B per annum (FY 2017)

Condition based maintenance (CBM) may alleviate these costs
- Past Years - Detect and repair
- Future – Sense and prevent

Corrosion Prognostics with AFRL are developing/testing a system to achieve this, consisting of:
  - Corrosion and Environmental Monitoring System (CEMS 3000)
  - Prognostic Atmospheric Corrosion Modeling and Analytics (PACMAN) computer application

Current model accounts for general and localized corrosion
Corrosion problems will get worse as aircraft become more sophisticated and greener (no chromates)
Atmospheric Corrosion Environment

• To be able to predict atmospheric corrosion accurately you need to understand the environment, that is:
  • Dynamic with changes in precipitation, temperature, relative humidity (RH), wind, solar radiation and pollutant deposition
  • These can result in metal surface wetness that constitute electrochemical corrosion cells
  • The corrosion cell is also dynamic and undertakes changes in:
    • It size, depth and metal area covered
    • Its chemical composition, speciation and concentrations
Measuring the Atmospheric Environment

• There are several ways to measure the atmospheric environment, using:
  • Sensors: Temperature (ambient and surface), RH, and time of wetness, localized to structures
  • Meteorological data: Temperature (ambient), RH, and precipitation amounts, large area measurements
  • Pollutant deposition data: Wet deposition kinetics, speciation, and concentrations, large area measurements

• No one method can give complete corrosion specific data
• Corrosion models are required to use data synergistically
Airbase (AB) Atmospheric Analytics

**Andersen AFB, Pacific Ocean, tropical marine**
- Distance from ocean: 1.5 miles
- Predominant salt types: NaCl, MgCl$_2$, Na$_2$SO$_4$
- Acidity: Average pH 5.56
- Wet deposition rate: 44.3 mg/day
- Rain water concentration: 4.78 mg/l
Atmospheric Modeling Pollutant Level

- Pollutant deposition data were combined with meteorological data to predict the speciation and dynamic surface pollutant densities.
Corrosion & Environmental Measurement System (CEMS)

Aim: Develop a prognostic model for corrosion analysis to:
- Increase A/C availability, effect predictive maintenance and data analytics

Model development: 5 locations in different climates
- WPAFB, OH – industrial
- Key West, FL – marine
- Luke AFB (Phoenix, AZ) – dry, high pollutant conc.
- Hill AFB (Salt Lake City, UT) – cold, industrial
- Kaneohe Bay, HI – coastal, hot

Duration: 18 months

- CEMS-3000
- Almost Maintenance-free
- **Extreme weather events:**
- CMS can be easily moved by two people
- Panel swap-out every 3 months

**Construction:** Al frame
**Power Reqs:** None
**Dimensions:**
- W: 4 ft
- D: 2 ft
- H: 4 ft

**Sensor details:**
- Solar Panel
- Data Logger / Battery / Temp-RH / 3G SIM
- AA2024 Bare and coated
- Time-of-Wetness / Surface temp sensors
- Steel resistance sensors
- Steel mass loss coupons

**Graph:**
- Steel corrosion sectional losses plotted with TOW data to show correlations

**Graph Parameters:**
- Time (weeks)
- Sectional loss (µm)
- Time of wetness sensor current (mA)
Prognostic Atmospheric Corrosion Modelling and ANalytics (PACMAN)

- Modeling uses environmental data gathered from sensors and/or, meteorological and pollution deposition data: Data is required to be historically complete
- Corrosion models determine corrosion severities using linked initiation and growth algorithms

Diagram:
- **Sensors**
  - TOW (USN)
  - Corrosion
  - Structure temp.
  - Atmospheric temp. + RH

- **Environment Model**
  - Pollutant types, Concentrations, Surface moisture

- **Droplet coalescence**
  - Individual corrosion cell sizes
  - Oxygen reduction kinetics

- **Corrosion Initiation**
  - Localised pitting
  - General (wet)

- **Corrosion Growth**
  - Individual pit sizes
  - Weight loss

- **Meteorological and Pollutant Deposition Data**
  - RH, temp, rain
  - Pollutant deposition rates, Pollutant ionic composition
Corrosion Model: Steel AB severity

- Corrosion weight loss for sites calculated by models and compared to available measured rates
- Good agreement between modeled and measured rates, where matching data was available
- Variation in corrosion rates for different periods were significant both for modeled and measured
- Sharp increases in corrosion amounts due to extended periods of wetness
Corrosion Model: Pitting validation

- Previous aluminum pitting corrosion data, from atmospherically exposed location
- Predictions made using sensor data
- Prediction with new improved model are more accurate

![Graph comparing pit size predictions](image1)

**Old model**

*Equation: $y = a + bx$*

- Weight: No Weighting
- Residual Sum of Squares: 384.051
- Pearson's r: 0.98183
- Adj. R-Square: 0.96121

**New model**

*Equation: $y = a + bx$*

- Weight: No Weighting
- Residual Sum of Squares: 210.80459
- Pearson's r: 0.99584
- Adj. R-Square: 0.9914
Washing Effect on Pollutant Levels

Andersen

Washing Frequency
- 30 days
- 14 days
- 7 days
- 3 days
- 1 days

Total pollutant level (mg/m²)

Time (days)

Tinker

Washing Frequency
- no wash days
- 90 days
- 60 days
- 30 days
- 14 days
- 7 days
- 3 days
- 1 days

Total pollutant level (mg/m²)

Time (days)

Eglin

Washing Frequency
- 90 days
- 60 days
- 30 days
- 14 days
- 7 days
- 3 days
- 1 days

Total pollutant level (mg/m²)

Time (days)

WPAFB

Washing Frequency
- no wash days
- 90 days
- 60 days
- 30 days
- 14 days
- 7 days
- 3 days
- 1 days

Total pollutant level (mg/m²)

Time (days)
Corrosion Model: Largest Pit AB washing

Largest pit diameter (µm) vs. Wash cycle period (days)

- Andersen
- Eglin
- Tinker
- WPAFB

The graphs illustrate the relationship between the largest pit diameter (in micrometers) and the wash cycle period (in days) for different locations: Andersen, Eglin, Tinker, and WPAFB. The data shows an increasing trend for all locations as the wash cycle period increases, indicating a potential correlation between the two variables for each location.
Corrosion Model: Steel AB Washing

Andersen

Eglin

Tinker

WPAFB
Questions