# ACES

## Accelerated Corrosion Expert Simulator

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# Report Documentation Page

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# Background Information

## SBIR Contract (Year 3 of a 3-year effort)

## Stakeholders:

### Government:

- Army/TARDEC Materials Group
- Army/TARDEC/RDECOM S&M Group
- Navy/USMC

### Industry:

- General Motors Proving Grounds (Commercial)
- Oshkosh Truck Corporation (MTVR, JLTV)
- GDIT (MRAP, JLTV, EFV)
- Northrop Grumman (Shipbuilding)

### Others:

- GCAS Inc
- Elzly Technology Corp
- RB Corrosion
- University of Akron

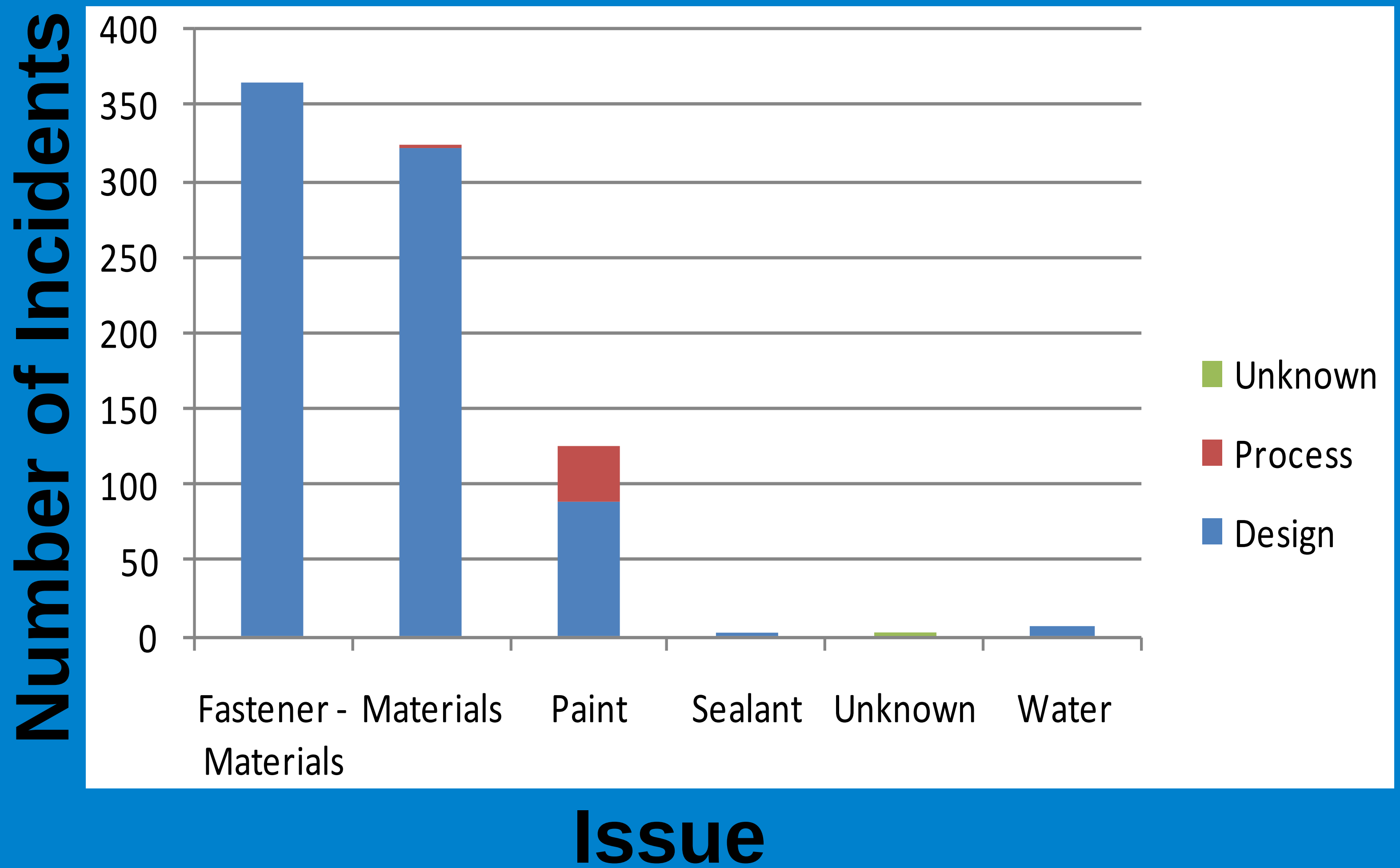
# ACES Objectives

- Fully Functional Vehicle Corrosion Prediction Simulation Code
- Simulate Coating & Corrosion Performance in Various Scenarios
- Forecast & Display Deterioration of Vehicle System over Time

# Accelerated Corrosion Durability Test

# Why do we need a Simulator?

## FMTV ACDRT Relationship of Issue and Cause



# Full Scale Vehicle Corrosion S&M

- Non-existent for Corrosion Predictions
- Design fixes must wait for ACDRT
- ACDRT is
    - Very Expensive
    - Too Late in the Design Cycle
    - Not Representative of Field Experience for Certain Materials

# Advantages of a Simulation Tool?

- Advanced Insight into Potential Problems
- Reduce ACDRT
- Knowledge Retention:
  - ❖ In 3-years = New Hire Graduate Engineer
  - ❖ Continues to learn and get smarter (if Taught!)
    - ➢ Lessons Learned
    - ➢ Field Experience
    - ➢ Validation / Calibration with Test Data
  - ❖ Never Retires
    - ➢ 10-years = Expert Tool with Superior Knowledge

# Army Materials & USMC Goals

- Determine Compliance of the Design with Contractual Requirements
- Validate that the Design will achieve the desired Service Life

# Army S&M Goals

- Armor Impact Methodology Development End-to-End Modeling & Simulation
- Provide Engineering-level & Physics-based Models of Corrosion Degradation to support:
  - Evaluation,
  - Technology down-selects, and
  - Design Optimization
- Probability Distribution showing likelihood to Failure

# Industry Goals

Acquire a simulation tool for use in:

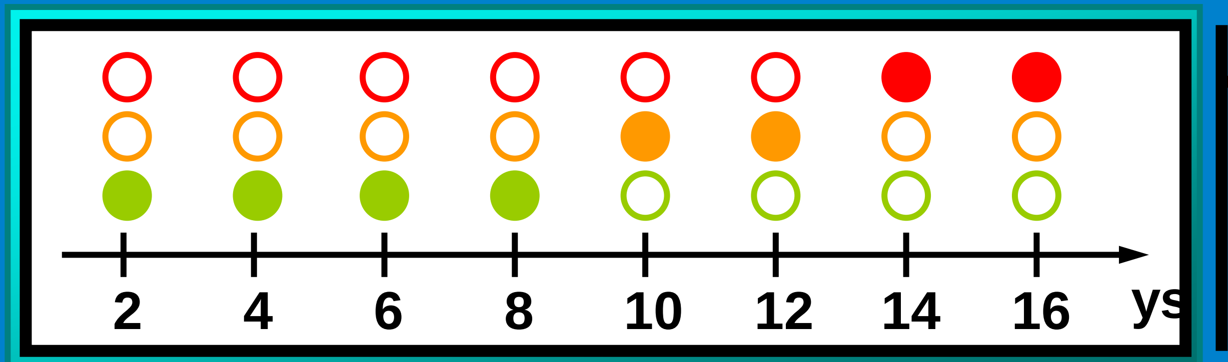
- Fast review of Corrosion Vulnerabilities in New Designs
- Assist in Designing Corrosion Tests
- Evaluation of New Technology

# Expected ACES Outcomes

- Specify/Select Optimal Design/Materials during Design/Fabrication of New Vehicles
- Define Maintenance Intervals based on expected Performance
- More Accurate Budget for Coating Repair/ Replacement
- Possible Elimination or Reduction of Full System Corrosion Testing
- Perform “What-if” Analysis on Different Scenarios
- Shorten Product Development Cycle Time
- Realistic Simulation of Corrosion Deterioration over Time

# Outputs and Measures $Y_j$

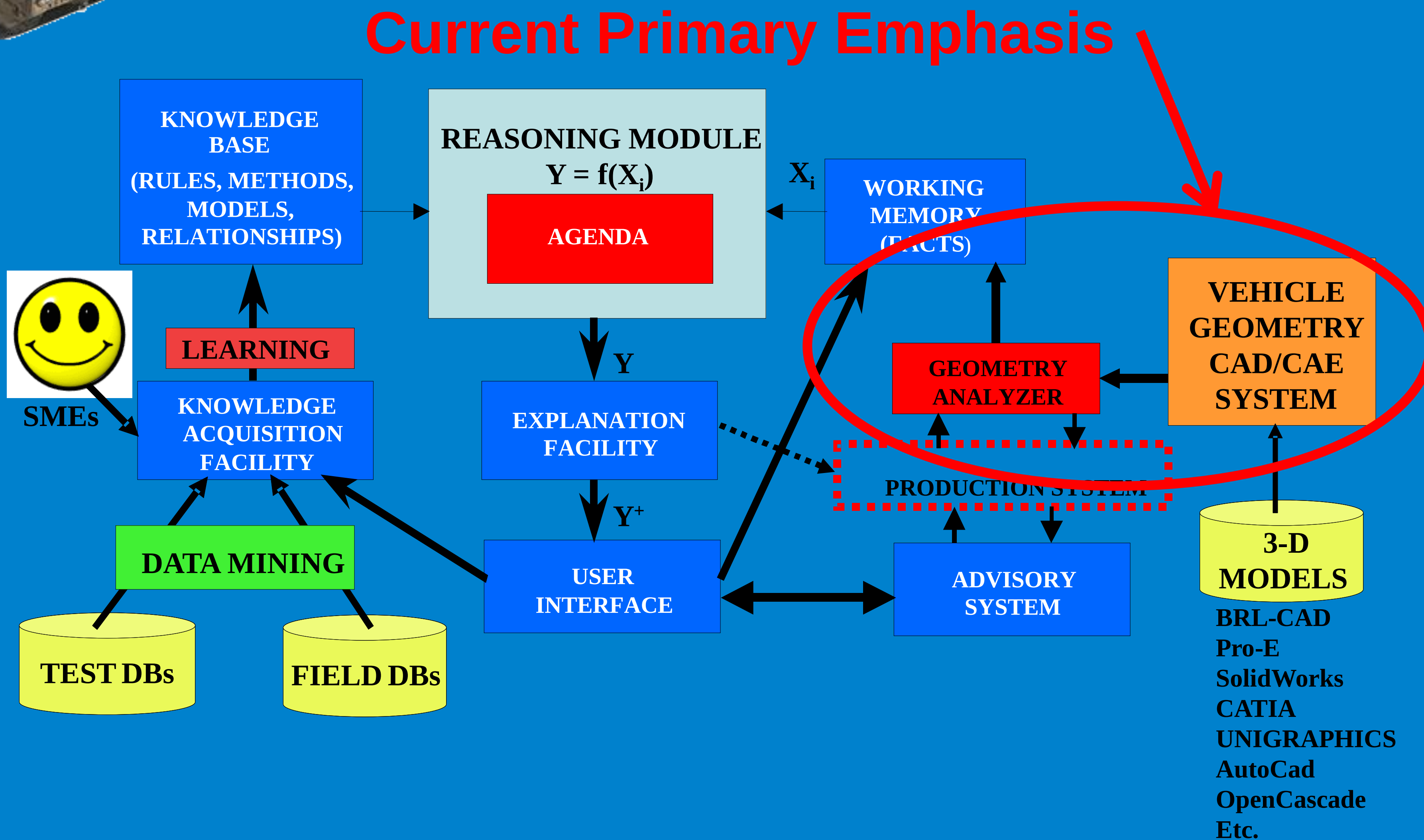
**Risk of Corrosion over Time**




- Sensitivity Analysis
- Advisory Capability

# Colorization of HMMWV Model

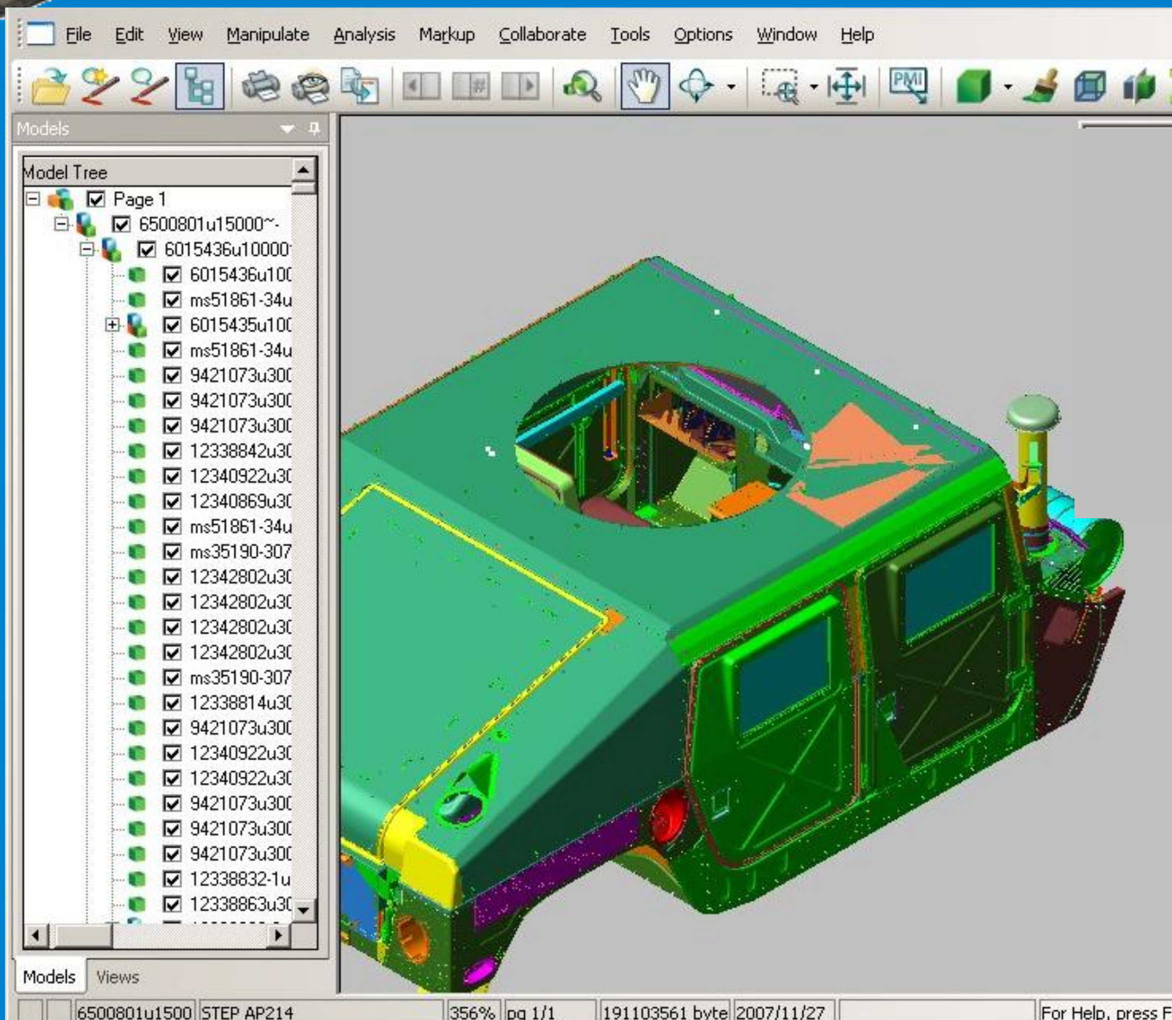
# ACES Architecture

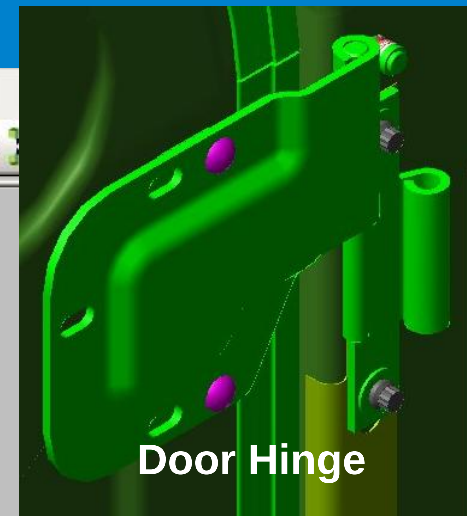


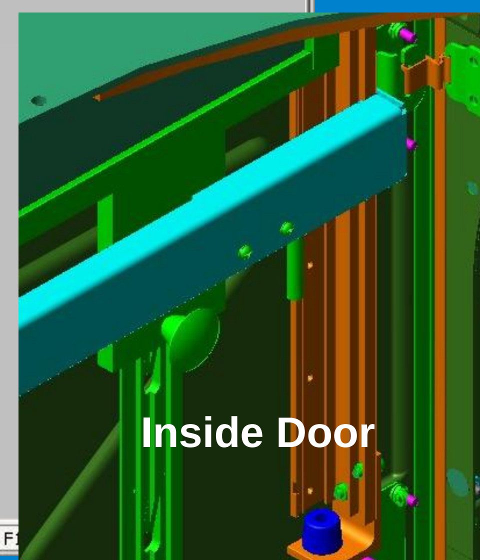
# Geometry is Key

- Import from CAD/CAE via STEP-AP214/203
  - Geometry Detail
  - Assembly Process
  - Material Properties
  - Fastener Details
- Other needed data
  - Insulation
  - Lubricants
- Geometry Display and Manipulation

# Models have Great Detail



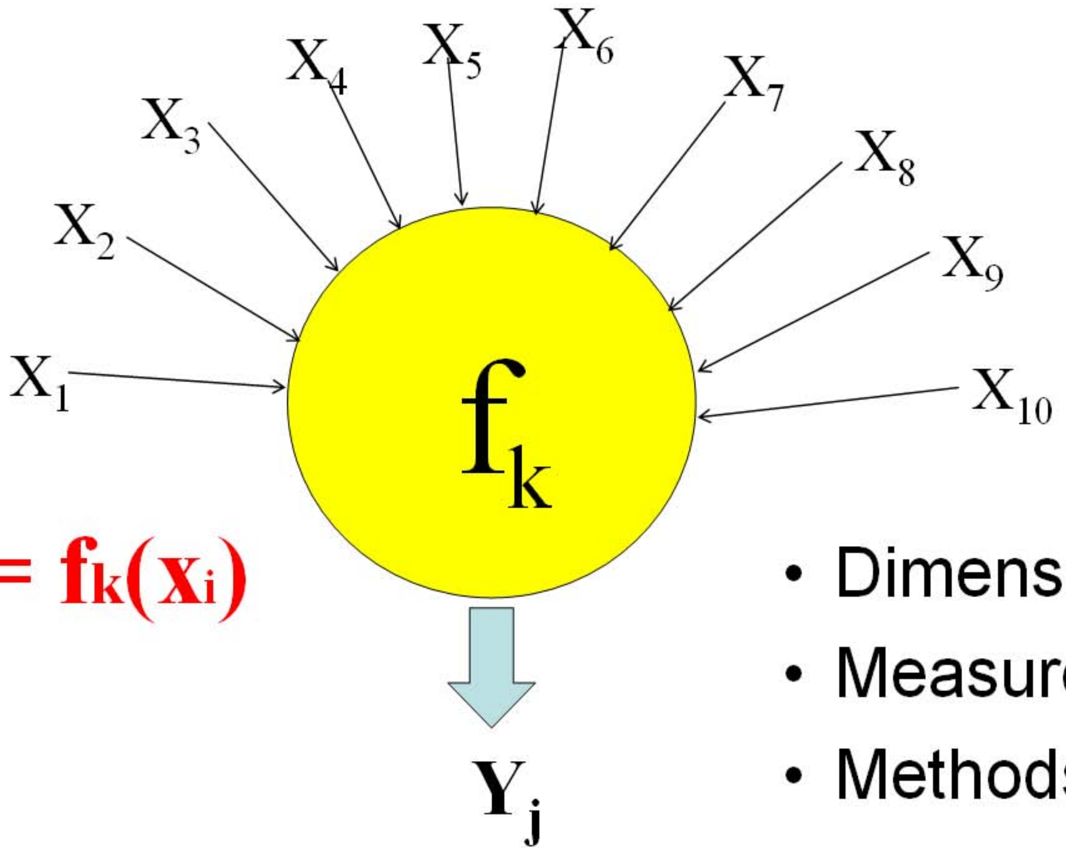



# Geometry Analyzer

- Advanced Feature Recognition Software to find Crevices, Entrapment Areas, etc:
  - High Performance Computer (HPC) or
  - Graphic Processing Units (GPU’s)
- “Follow the Water” (Water Intrusion/ Drainage)

# Modeling Approach




$$Y_j = f_k(x_i)$$

- Dimensions, $X_i$
- Measures, $Y_j$
- Methods, $f_k$

# Inputs and Dimensions $X_i$

**Geometry and Design**

- Lap Joints
- Welds
- Fasteners
- Crevices
- Entrapment Areas
- Water Intrusion
- Drainage
- Shielding
- Hermetic Seals
- Galvanic Coupling
- Area Ratio

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## Environment

- Humidity
- Salt Spray
- Mud
- Fording
- Dry Off
- Temperature
- UV Exposure
- Vibration
- Shock
- Stone Pecking
- Driving Miles
- Driving Terrain

## Maintenance Activities

- Wash
- Dry
- Lubricate
- Exercise Joints

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## Materials

- Metals and Alloys
- Metal Matrix
- Composites
- Cermets
- Non-Metals
- Plastics
- Rubbers
- Glass
- Ceramics
- Composites
- Coating Systems
- Organic
- Inorganic
- Ceramic

# Inputs and Dimensions $X_i$

## Metals and Alloys Properties
- Method of Manufacture
- Heat Treatment

## Plastics

## Metal Matrix Composites

## Cermets

## Coating Systems Properties
- Thermal Properties
- Surface Tension
- Strength
- Permeability
- Adhesion
- Integrity
  - Holidays
  - Porosity
  - Edge Coverage
- Hardness
- Impact Resistance
- Stone Pecking Resistance
- UV Resistance
- Undercutting Resistance
- Cracking Resistance
- Chemical Resistance
- Filiform Corrosion Resistance

## General Material Properties
- Thickness
- Hardness
- Strength
- Ductility
- Abrasion Resistance
- Temperature Resistance
- Corrosion Resistance
  - Passive or Active/Noble
  - Specific Resistance to Eight Forms of Corrosion

## Glass

## Composites (Non-Metallic)

## Rubbers

## Ceramics

# Models and Methods $f_k$

- Artificial Intelligence
  - Bayesian Networks
  - Rule-based Systems
- Statistics
  - Markov Chains
  - Turnbull / Weibull

### Metals and Alloys - Models

- General
- Galvanic
- Pitting
- Crevice
- Dealloying
- Stress Cracking
- Erosion
- Inter-granular
- Exfoliation
- Ceramic

### Coating Systems - Models

- Rust-through
  - Pinpoint
  - Irregular Surfaces
- Delamination
  - Undercutting
  - Corrosion Under Coating
  - Osmotic Blistering
  - Peeling
- Aesthetic Failure
  - Color Change
  - Gloss Loss
  - Embedded Dirt or Stain
- Erosion or Abrasion
  - Thickness Loss
  - Texture Change

### Fasteners and Hardware - Models

- Galvanic
- Crevice
- Thin/Damaged Plating or Coating
- Failure of Isolation Gaskets
- Failure of Sealants
- Material Metallurgy
- Strength-related Failure
- Jacking
- Seizing
- Stress

### Electronic Parts - Models

- Corrosion in External Connectors
- Failures in External Connectors
- Corrosion of Electronics
- Failure of Electronics

### Electrical Parts - Models

- Corrosion in Exposed Connectors
- Failures in Exposed Connectors

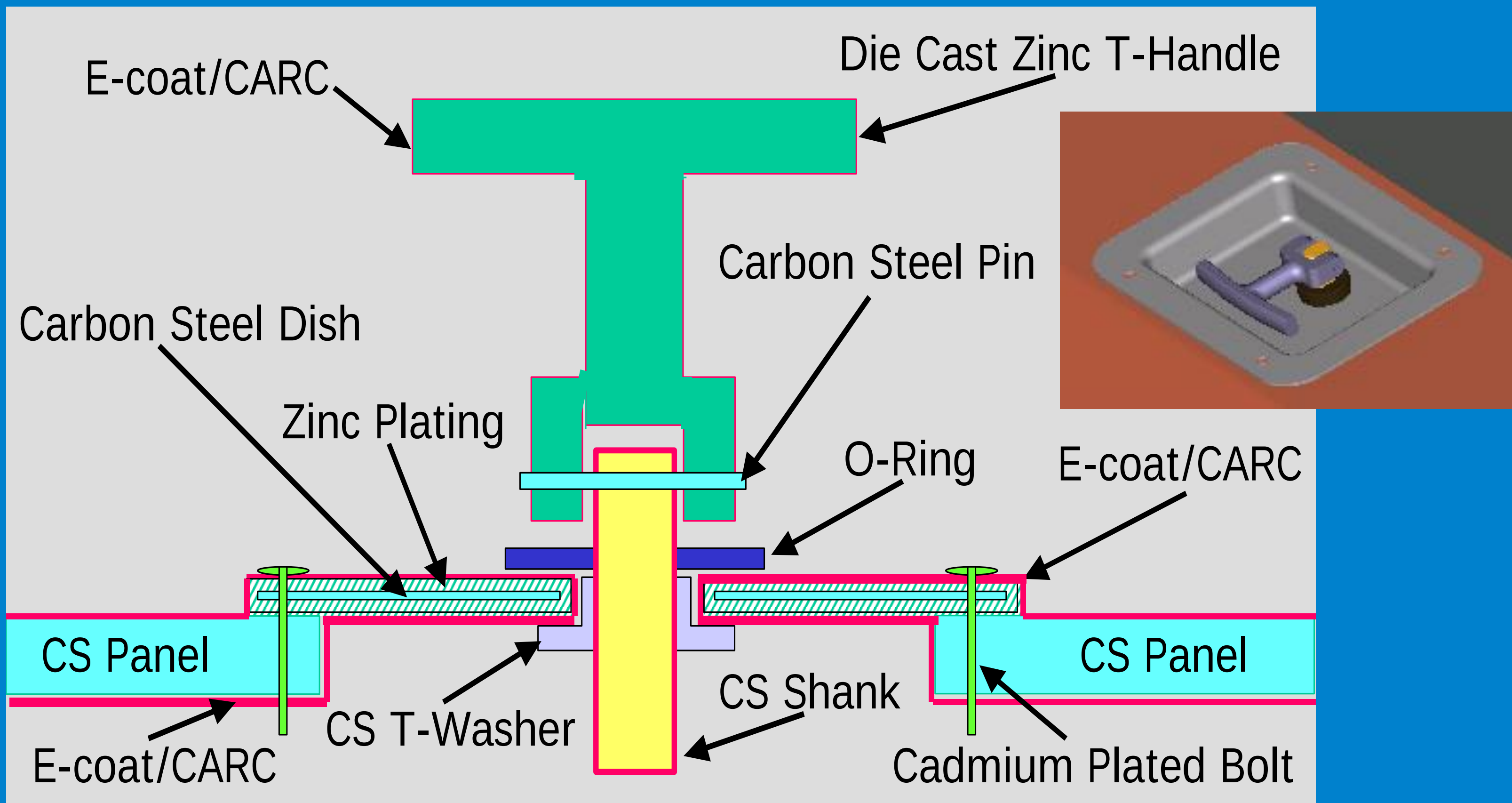
# Corrosion Modeling Emphasis

- General Corrosion
- Galvanic Corrosion
- Crevice Corrosion

# Status to Date

- General Architecture Design
- General Modeling Requirements
- Galvanic Corrosion Modeling (CES)
- Geometry Import, Viewing and Manipulation
- Geometry Analyzer Feature Recognition
- Computational Requirements: HPU/GPU

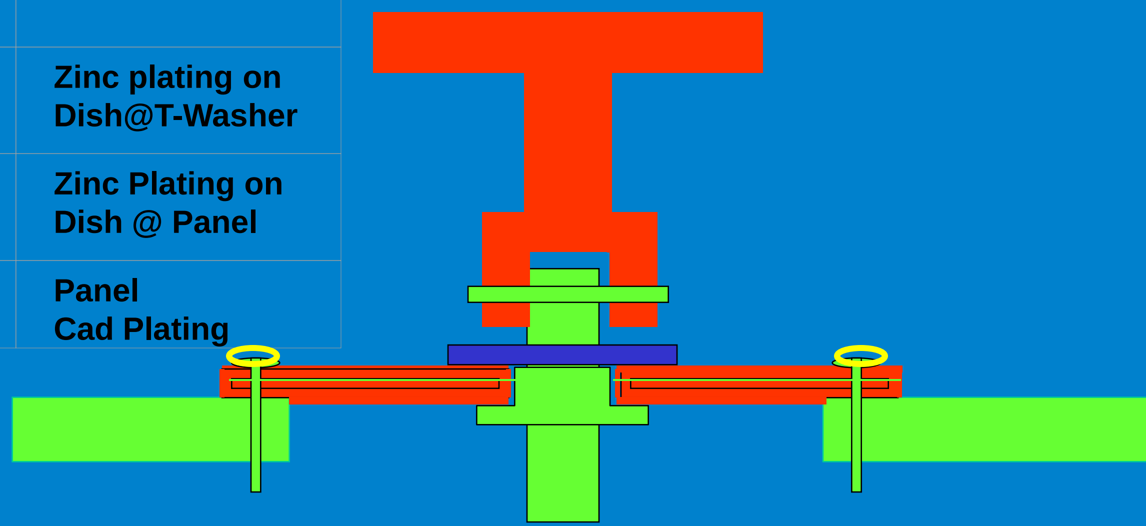
# Original (10-year ACT) Design



# Galvanic Corrosion Predictions

| Interacting Components | Original (10-year ACT) Design | |
|---|---|---|
| | Unacceptability | Corroding Part |
| T-Handle/Pin-Shank & T-Handle/Dish | 64.9% | T-Handle |
| T-Washer/Shank & T-Washer/Dish | 11.5% | Zinc plating on Dish@T-Washer |
| Dish/Panel | 59.5% | Zinc Plating on Dish @ Panel |
| Bolts/Dish & Bolts/Panel | 12.8%<br>30.6% | Panel<br>Cad Plating |

## 10 yr ACDRT



| Flag Color | Qualitative Assessment | Level of Unacceptable Galvanic Corrosion |
|---|---|---|
| Green | *Acceptable* | Less than 20% |
| Yellow | *Critical* | 20%-40% |
| Red | *Unacceptable* | Greater than 40% |

# Test Results 10 yr ACDRT