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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18
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

Simulated use by combing of corrosion and durability events. Corrosive electrolytes (i.e., salt solutions) applied to vehicle surfaces. Heat and humidity used to accelerate corrosion. Test durations up to 1-year.

ACDRT
Why do we need a Simulator?

FMTV ACDRT Relationship of Issue and Cause

Issue

- Fastener - Materials
- Paint
- Sealant
- Unknown
- Water

Number of Incidents

- Fastener - Materials
- Paint
- Sealant
- Unknown
- Water

Unknown
Process
Design
• 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
Risk of Corrosion over Time

- Sensitivity Analysis
- Advisory Capability
Colorization of HMMWV Model
**ACES Architecture**

**Current Primary Emphasis**

**Reasoning Module**

\[ Y = f(X_i) \]

**Agenda**

**Working Memory (Facts)**

**Explanatory Facility**

**Knowledge Base**

(Rules, Methods, Models, Relationships)

**Knowledge Acquisition Facility**

**Learning**

**Data Mining**

**User Interface**

**Explanation Facility**

**Geometry Analyzer**

**Advisory System**

**Vehicle Geometry CAD/CAE System**

**3-D Models**

BRL-CAD

Pro-E

SolidWorks

CATIA

UNIGRAPHICS

AutoCad

OpenCascade

Etc.

**SMEs**

**Field DBs**

**Test DBs**
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

Door Hinge

Inside Door
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, \( f_k \)
Geometry and Design

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

### 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
<table>
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<tr>
<th>Geometry and Design</th>
<th>Environment</th>
<th>Maintenance Activities</th>
<th>Materials</th>
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<td>Driving Miles</td>
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<td>Coating Systems</td>
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<td>Driving Terrain</td>
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<td>Inorganic</td>
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<td>Ceramic</td>
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Inputs and Dimensions $X_i$

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

**Plastics**

**Metal Matrix Composites**

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

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

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

Metals and Alloys - Models
General
Galvanic
Pitting
Crevice
Dealloying
Stress Cracking
Erosion
Inter-granular
Exfoliation
Ceramic

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

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
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

- **Material/Coating Configuration**
  - Die Cast Zinc T-Handle
  - Carbon Steel Pin
  - CS Shank
  - CS T-Washer
  - Carbon Steel Dish
  - E-coat/CARC
  - Zinc Plating
  - Cadmium Plated Bolt
  - E-coat/CARC
  - CS Panel
  - O-Ring

**E-coat/CARC**

**Die Cast Zinc T-Handle**

**Carbon Steel Pin**

**Zinc Plating**

**O-Ring**

**E-coat/CARC**

**CS Panel**

**CS Panel**

**CS T-Washer**

**CS Shank**

**Cadmium Plated Bolt**

**CS Panel**

**CS Panel**
## Galvanic Corrosion Predictions

### 10 yr ACDRT

<table>
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<th>Interacting Components</th>
<th>Original (10-year ACT) Design</th>
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<tr>
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<td>Unacceptability</td>
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<tr>
<td>T-Handle/Pin-Shank &amp;</td>
<td>64.9%</td>
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<tr>
<td>T-Handle/Dish</td>
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<tr>
<td>T-Washer/Shank &amp;</td>
<td>11.5%</td>
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<td>T-Washer/Dish</td>
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<tr>
<td>Dish/Panel</td>
<td>59.5%</td>
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<td>Bolts/Dish &amp; Bolts/Panel</td>
<td>12.8%</td>
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<th>Flag Color</th>
<th>Qualitative Assessment</th>
<th>Level of Unacceptable Galvanic Corrosion</th>
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<tr>
<td>Green</td>
<td>Acceptable</td>
<td>Less than 20%</td>
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<tr>
<td>Yellow</td>
<td>Critical</td>
<td>20%-40%</td>
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<tr>
<td>Red</td>
<td>Unacceptable</td>
<td>Greater than 40%</td>
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Test Results 10 yr ACDRT

T-handle latch, flush (panel stowage outside front) 11/29/95
Stage 3 TIR CT-E000325