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Curve-Crossing for Material Selection

ASETSDefense Workshop 2018-Denver, Colorado

Alan Rose, arose@corrdesa.com

Keith Legg, klegg@corrdesa.com

Siva Palani, spalani@corrdesa.com

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Agenda

1. Corrosion Djinn™ development (computational curve crossing)
2. VV&A - Verification Validation and Accreditation
3. CAE modeling-Thin film galvanic corrosion

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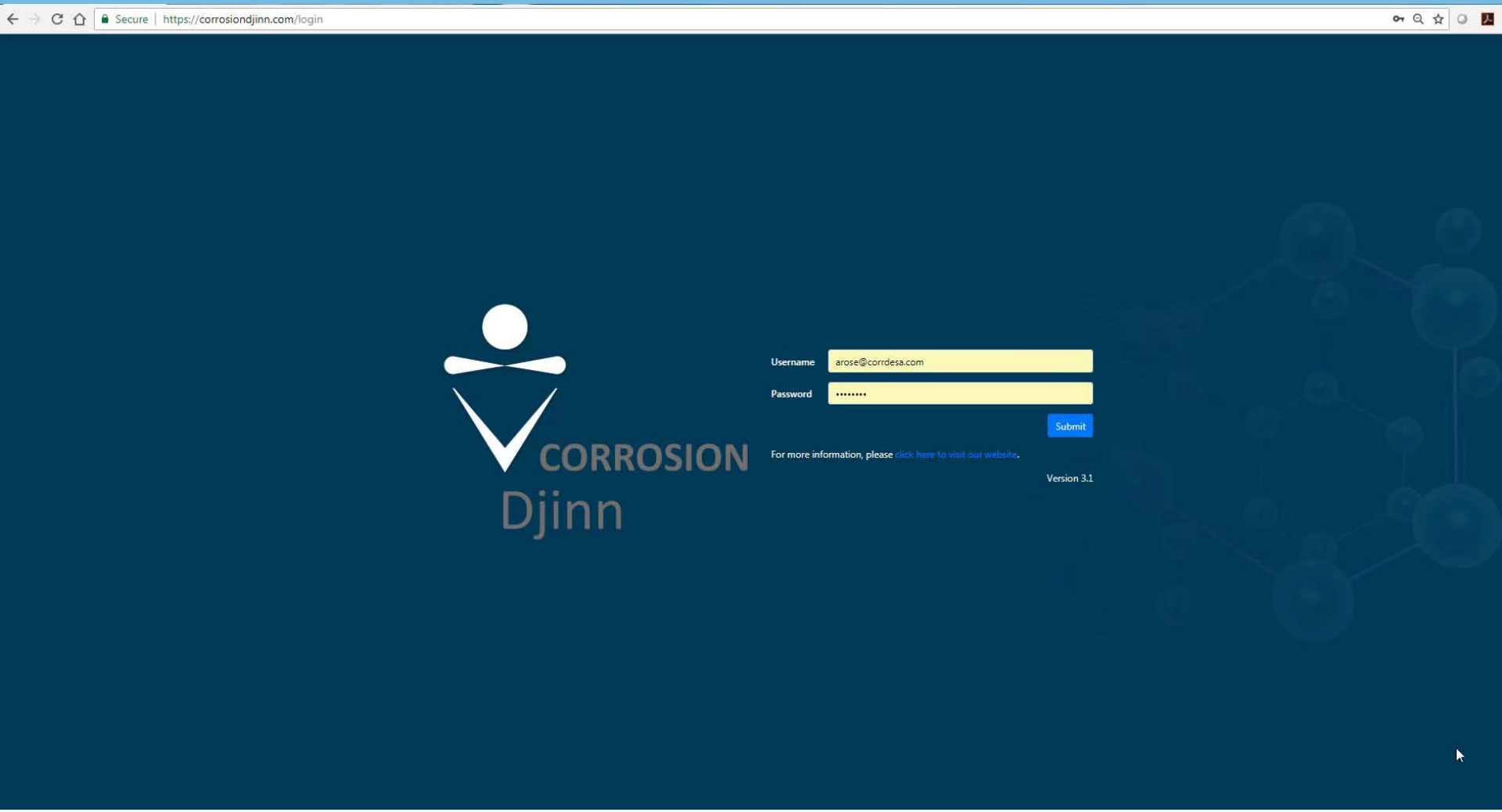
Corrosion Djinn Version 3.1



MP MATERIALS PERFORMANCE CORROSION INNOVATION OF THE YEAR AWARDS - WINNER 2017 -

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https://corrosiondjinn.com/

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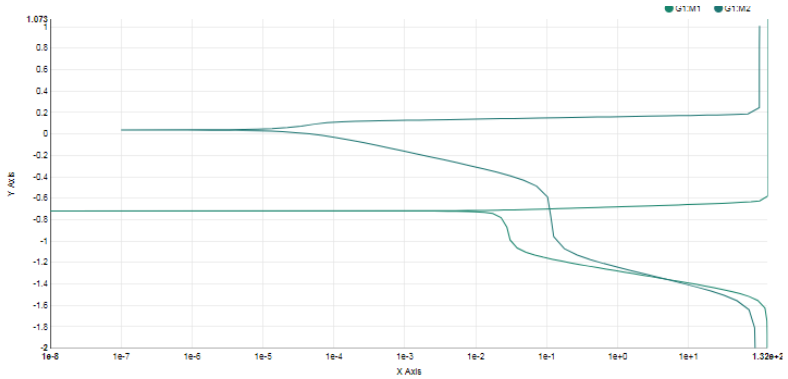
Corrosion Djinn

- Principle is the well-known Mixed – potential /curve crossing technique
  - Crossing point of curves of V vs ABS(J) shows mixed potential and interfacial galvanic current
  - In-line with next gen. MIL-STD-889
- Strictly, assumes 2 parallel surfaces of equal area in bulk solution with high conductivity
  - Predicts **self** and **galvanic corrosion rate** based on galvanic current
  - In practice it works well with non-parallel surfaces and thin films (with the thin film polarization data)



Group 1 +

Material Group

Modify Copy

Environment	3.5% NaCl

Material 1 (Anode)

Substrate	Al
Designation	7075-T6
Coating	None
Treatment	None

OCP	-7.18e-1 V_{SCE}
Self Corrosion Rate	1.84e+1 microns/year
	7.35e-1 mils/year
Galvanic Acceleration Factor	6.72e+0

Material 2 (Cathode)

Substrate	Stainless steel
Designation	15-5 PH
Coating	None
Treatment	None

OCP	3.79e-2 V_{SCE}
Self Corrosion Rate	3.57e-2 microns/year
	1.43e-3 mils/year
Galvanic Acceleration Factor	

Potential Difference	7.56e-1 V
Mixed Potential	-7.00e-1 V_{SCE}
Galvanic Corrosion Current Density	1.10e-1 Am^{-2}
Galvanic Corrosion Rate	1.23e+2 microns/year
	4.94e+0 mils/year

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Identifies anodic and cathodic materials

Group 1 +

Material Group

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Environment 3.5% NaCl

Material 1 (Anode)

Substrate	Al
Designation	7075-T6
Coating	None
Treatment	None

OCP	-7.18e-1 V_{SCE}
Self Corrosion Rate	1.84e+1 microns/year
	7.35e-1 mils/year
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Reports Open Circuit Potentials (OCP)

Group 1 +

Material Group

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Environment 3.5% NaCl

Material 1 (Anode)

Substrate	Al
Designation	7075-T6
Coating	None
Treatment	None

OCP	-7.18e-1 V_{SCE}
Self Corrosion Rate	1.84e+1 microns/year
	7.35e-1 mils/year
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Material 2 (Cathode)

Substrate	Stainless steel
Designation	15-5 PH
Coating	None
Treatment	None

OCP	3.79e-2 V_{SCE}
Self Corrosion Rate	3.57e-2 microns/year
	1.43e-3 mils/year
Galvanic Acceleration Factor	

Potential Difference	7.56e-1 V
Mixed Potential	-7.00e-1 V_{SCE}
Galvanic Corrosion Current Density	1.10e-1 Am^{-2}
Galvanic Corrosion Rate	1.23e+2 microns/year

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Reports potential difference (ΔE)

Group 1 +

Material Group

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Environment 3.5% NaCl

Material 1 (Anode)

Substrate	Al
Designation	7075-T6
Coating	None
Treatment	None

OCP	-7.18e-1 V_{SCE}
Self Corrosion Rate	1.84e+1 microns/year
	7.35e-1 mils/year
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Material 2 (Cathode)

Substrate	Stainless steel
Designation	15-5 PH
Coating	None
Treatment	None

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Self Corrosion Rate	3.57e-2 microns/year
	1.43e-3 mils/year
Galvanic Acceleration Factor	

Potential Difference	7.56e-1 V
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Galvanic Corrosion Rate	1.23e+2 microns/year

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Reports **self corrosion rates**

Corrosion Rate Calculation:

1. Corrosion current extracted from deconvoluted polarization curves

2. Calculate corrosion rate based on EW based on ASTM G102 (Standard Practice for Calculation of Corrosion Rates)

Group 1 +

Material Group

Modify Copy

Environment 3.5% NaCl

Material 1 (Anode)	
Substrate	Al
Designation	7075-T6
Coating	None
Treatment	None
OCP	-7.18e-1 V_{SCE}
Self Corrosion Rate	1.84e+1 microns/year
	7.35e-1 mils/year
Galvanic Acceleration Factor	6.72e+0

Material 2 (Cathode)	
Substrate	Stainless steel
Designation	15-5 PH
Coating	None
Treatment	None
OCP	3.79e-2 V_{SCE}
Self Corrosion Rate	3.57e-2 microns/year
	1.43e-3 mils/year
Galvanic Acceleration Factor	

Potential Difference	7.56e-1 V
Mixed Potential	-7.00e-1 V_{SCE}
Galvanic Corrosion Current Density	1.10e-1 Am^{-2}
Galvanic Corrosion Rate	1.23e+2 microns/year

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Reports **galvanic corrosion rate & acceleration factor**

Despite low self-corrosion, galvanic couple **accelerates** the corrosion

Group 1 +

Material Group

Modify Copy

Environment 3.5% NaCl

Material 1 (Anode)

Substrate	Al
Designation	7075-T6
Coating	None
Treatment	None

OCP	-7.18e-1 V_{SCE}
Self Corrosion Rate	1.84e+1 microns/year
	7.35e-1 mils/year
Galvanic Acceleration Factor	6.72e+0

Material 2 (Cathode)

Substrate	Stainless steel
Designation	15-5 PH
Coating	None
Treatment	None

OCP	3.79e-2 V_{SCE}
Self Corrosion Rate	3.57e-2 microns/year
	1.43e-3 mils/year
Galvanic Acceleration Factor	

Potential Difference	7.56e-1 V
Mixed Potential	-7.00e-1 V_{SCE}
Galvanic Corrosion Current Density	1.10e-1 A/m^2
Galvanic Corrosion Rate	1.23e+2 microns/year

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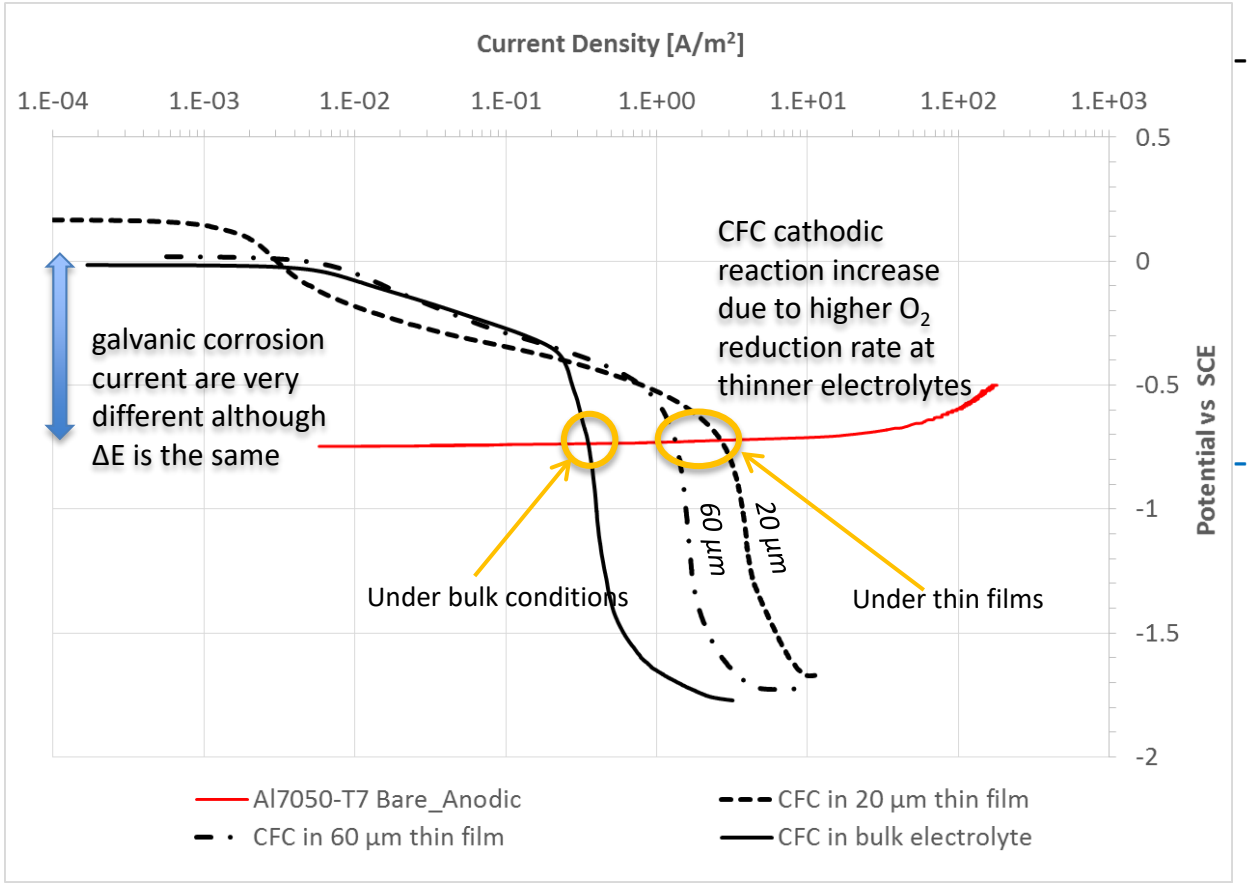
Impact of environment on corrosion



- ***Corrosion Djinn™*** also captures the electrochemical kinetics increase of material due to change in electrolyte thickness from e.g. submerged to atmospheric conditions.
- Thin electrolytes (condensates) increase corrosion often by ~10x

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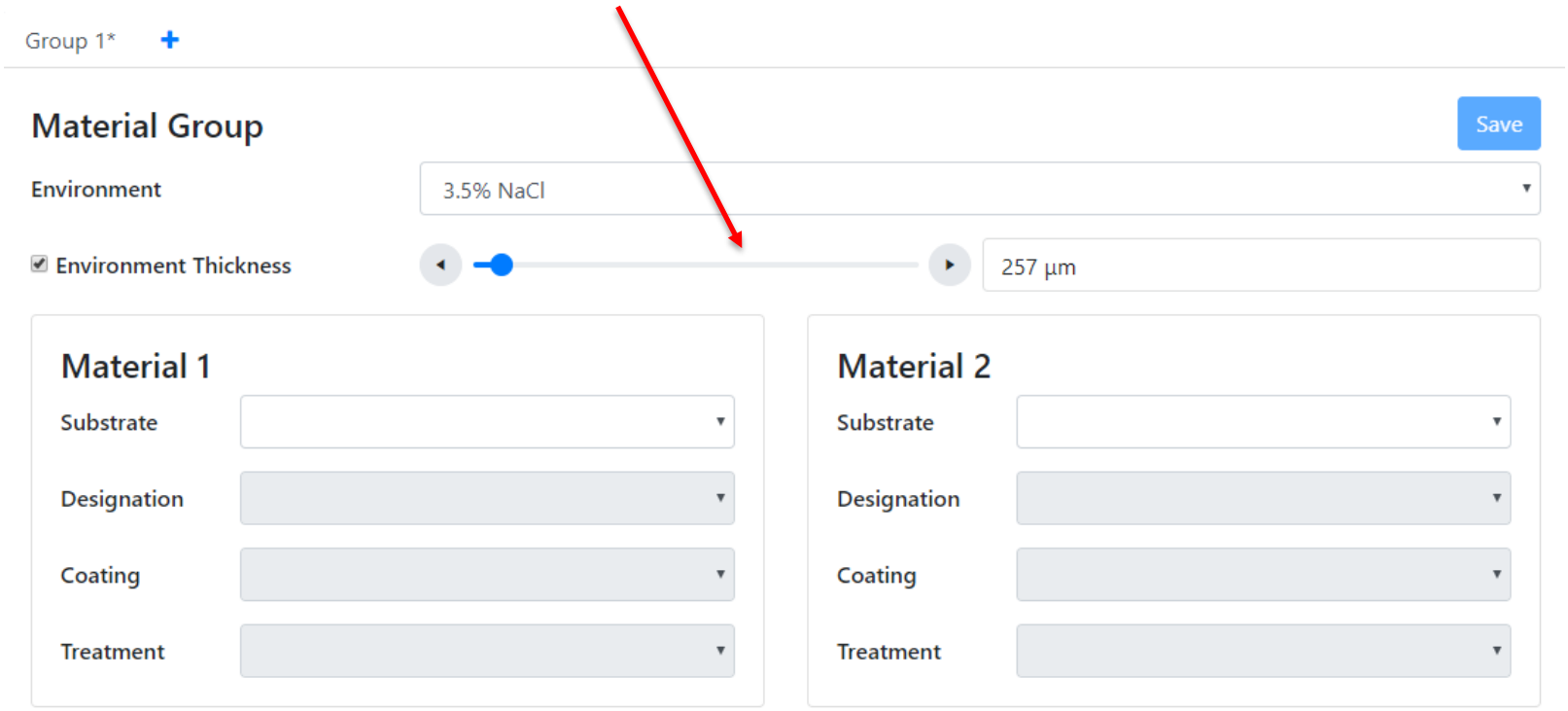
Film Thickness Variation(Under testing)

Slider- Allowing user to choose desired electrolyte thickness



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Added improvements from the previous version

Capabilities:

- ✓ Corrosion rate (Echem. equivalents table):
  - ✓ Self corrosion rate
  - ✓ Galvanic corrosion rate
- ✓ Galvanic Acceleration Severity Factor:
  - ✓ Galv. corr./OCP self-corr.
- ✓ Framework for Electrolyte thickness variation (under testing)
- ✓ Framework for new environment
- ✓ Additional materials

Deployment:

- ✓ Standalone (tested)
  - ✓ Same commercial database, but behind customer firewall
  - ✓ Proprietary augmentation of electrochemical database
- ✓ Standalone Server (under development)
  - ✓ Same commercial database, but behind customer firewall
  - ✓ Proprietary augmentation of electrochemical database
  - ✓ Multiple users – managed by customer

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Planned additions in the present phase

- Additional materials, coatings, treatments (more measurements ongoing and fitting)
- Impact of Area ratios (feasibility study)
- Different environment (electrolyte chemistry)
- Common geometries with visual corrosion severity and extent

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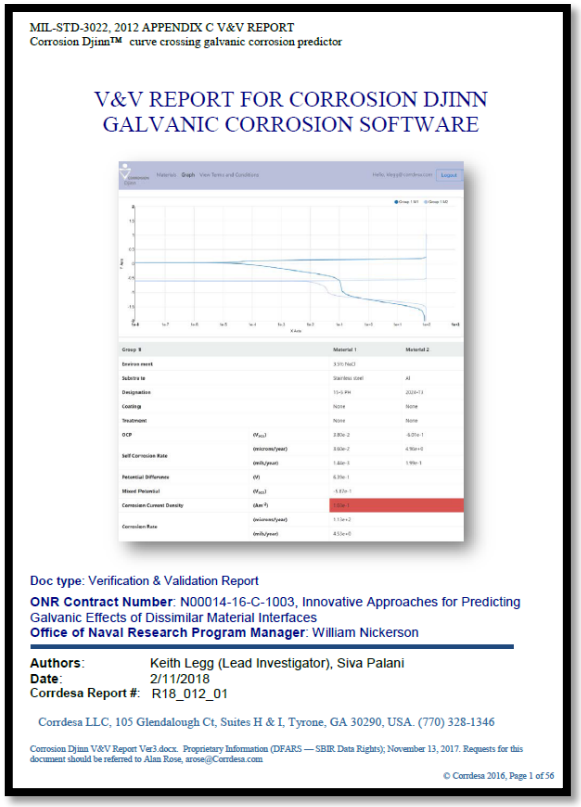
Verification Validation and Accreditation

- Validation Plan and Report for Corrosion Djinn IAW MIL-STD-3022 is done
  - NAVAIR PAX to obtain Accreditation and install initially onto an R&D computer at PAX. They form the basis for the Accreditation Report.
- Verification
  - Curve crossing (mix-potential approach) works correctly
- Validation
  - Curve crossing is a well-stablished technique
  - Quantitative data validation vs CAE and experimental data
  - Qualitative data validation vs NAVAIR galvanic assemblies



MIL-STD-3022, 2012 APPENDIX C V&V REPORT
Corrosion Djinn™ curve crossing galvanic corrosion predictor

V&V REPORT FOR CORROSION DJINN
GALVANIC CORROSION SOFTWARE

Doc type: Verification & Validation Report
ONR Contract Number: N00014-16-C-1003, Innovative Approaches for Predicting Galvanic Effects of Dissimilar Material Interfaces
Office of Naval Research Program Manager: William Nickerson

Authors: Keith Legg (Lead Investigator), Siva Palani
Date: 2/11/2018
Corrdesa Report #: R18_012_01

Corrdesa LLC, 105 Glendalough Ct, Suites H & I, Tyrone, GA 30290, USA. (770) 328-1346

Corrosion Djinn V&V Report Ver3.docx. Proprietary Information (DFARS — SBIR Data Rights); November 13, 2017. Requests for this document should be referred to Alan Rose, arose@Corrdesa.com

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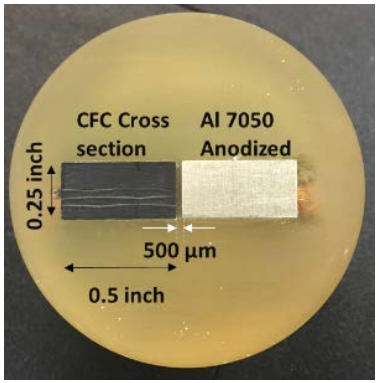
Quantitative Validation

- Validation Report
  - Quantitative data validation

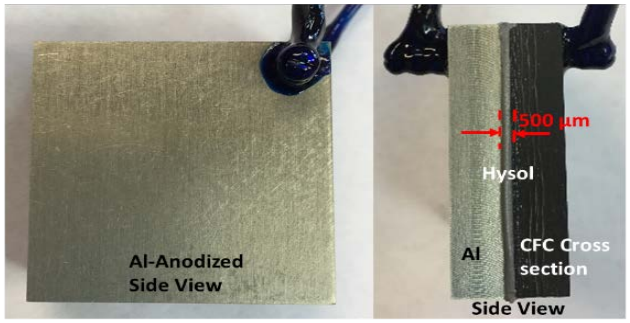
Coplanar



	Total volume loss (mm^2)		
	Measured	CAE/FEA	Djinn
Bare 7050 Al	0.842	1.253	1.25
SAA 7050 Al	1.3	1.357	1.1

Non-planar "sandwich"

CFC-Al 7050 Anodized-Hysol joint



	Total current (Am^{-2})		
	Measured	CAE/FEA	Djinn
SAA 7050 Al Day 1	2.5E-4	2.46E-4	3.5E-4
SAA 7050 Al Day 30	2.45E-4	2.63E-4	4.8E-4

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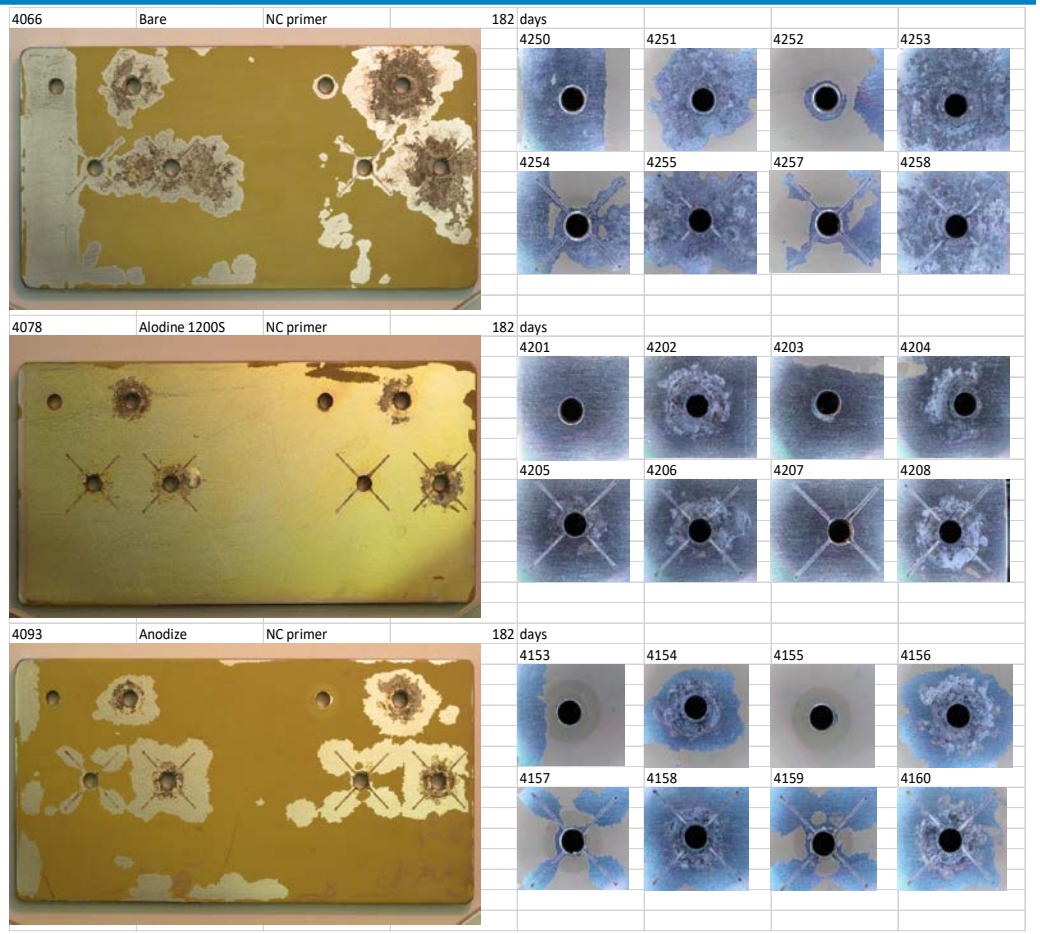
Qualitative Validation



PAX galvanic assembly data

Group 1	Material 1	Material 2
Substrate	Al	Stainless steel
Designation	2024-T3	316 (NAVAIR PAX)
Coating	SAA	None
Treatment	Anodize seal Cr6	None
OCP (V_{SCE})	-0.692967	-0.141998768
Potential Difference (V)	0.5509682	
Mixed Potential (V_{SCE})	-0.448594749	
Corrosion Current Density (Am^{-2})	0.0100762555	

Group 2	Material 1	Material 2
Substrate	Al	Titanium
Designation	2024-T3	Ti6Al4V
Coating	None	None
Treatment	Alodine 1200	Annealed, etched per BAC5753
OCP (V_{SCE})	-0.594999969	0.0331550166
Potential Difference (V)	0.628155	
Mixed Potential (V_{SCE})	-0.5910357	
Corrosion Current Density (Am^{-2})	0.00158223929	

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Corrosion Djinn users

- Defense
  - Used as part of Corrosion Analysis for new USAF H-60 (Sikorsky)
  - Used on F-18 landing gear (NAVAIR)
  - Part of Corrosion Design Toolbox for composite/Al systems (USAF/WPAFB)
- Commercial
  - Replacing chromates on commercial products (Emerson Electric)
  - Corrosion design for consumer electronics (Electronics company)
  - Corrosion design for systems to be used on or near ocean (Aerospace/Space company)

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CAE modeling (Thin film-Wetting)

Key parameters:

- Film thickness (and its variation) on the cathodic member
- Relevance of polarization curves used

Work Done:

- Modeling of galvanic corrosion behavior between CFC-Al7050 joint under uniform thin film conditions
- Predicting variable film thickness on complex geometries using CFD and then model corrosion
- Experimental verification with B117 Accelerated corrosion test and corrosion depth measurements

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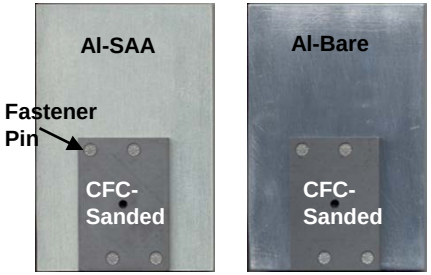
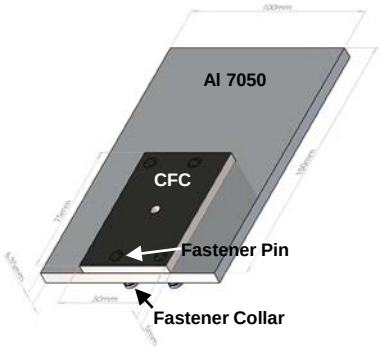
Experimental Approach (Accelerated Test)

Sample Design



Case 1 Case 2



Designed to simulate lap joint to capture both galvanic and self corrosion behavior

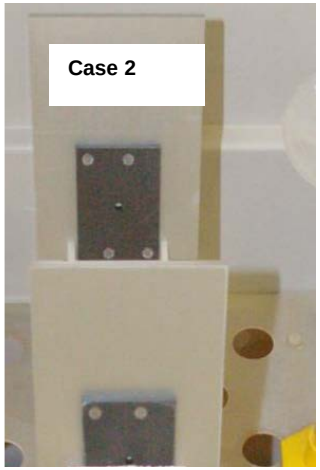
Test Cases

	Material A	Material B	Material C	Material D
	(15x10 cm)	(7.5x5 cm)	(Fastener Pin)	(Fastener Collar)
Test Case	AA 7050-T7451	CFC	Ti-6Al-4V	Ti-3Al-2.5V
1	Bare	sanded	degreased	degreased
2	Anodized (SAA)	sanded	degreased	degreased

Test conditions

ASTM B117 Constant Salt Fog Test in Q-Fog Chamber (for 1 month):

- At 35 °C
- 3.5 wt.% NaCl
- Conductivity: ~ 50000 µS/cm
- 6.5 < pH < 7.5
- 22 ° from vertical



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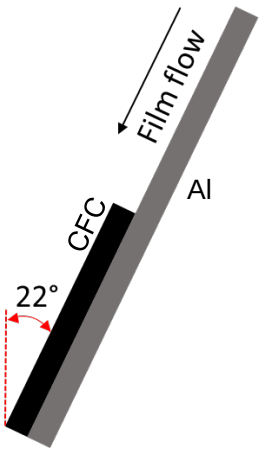
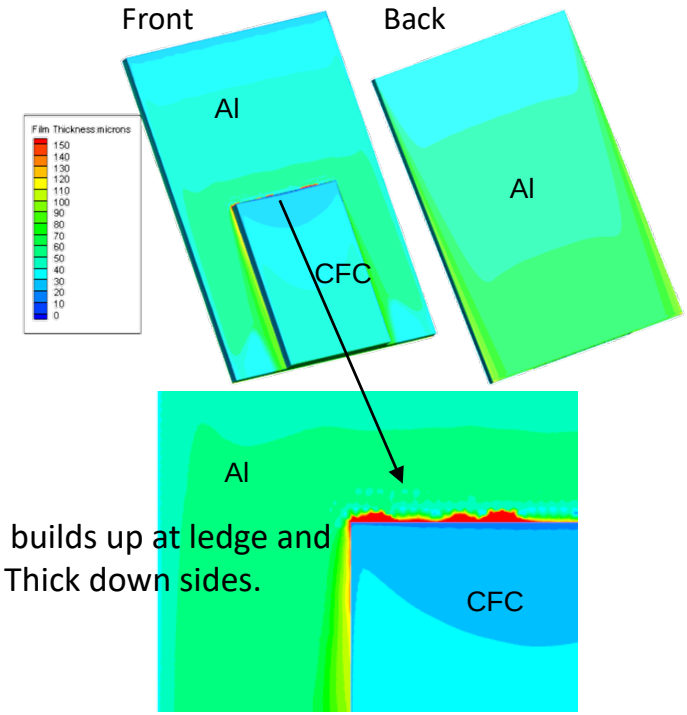
Results (Fluid Film Modeling)

Side View:

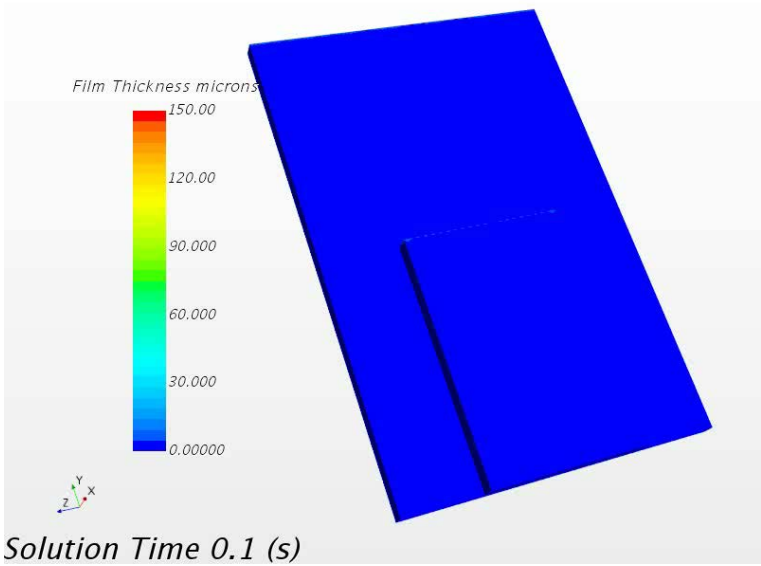


Front & Back View:



Electrolyte builds up at ledge and spills over. Thick down sides.

Electrolyte flows down back of Al plate, increasing in thickness



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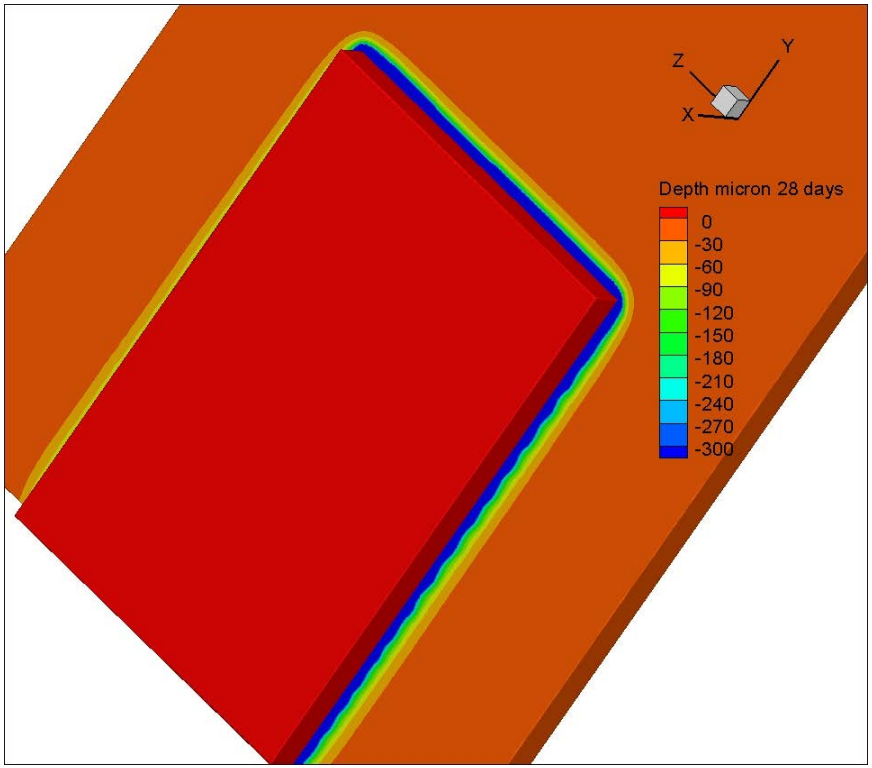
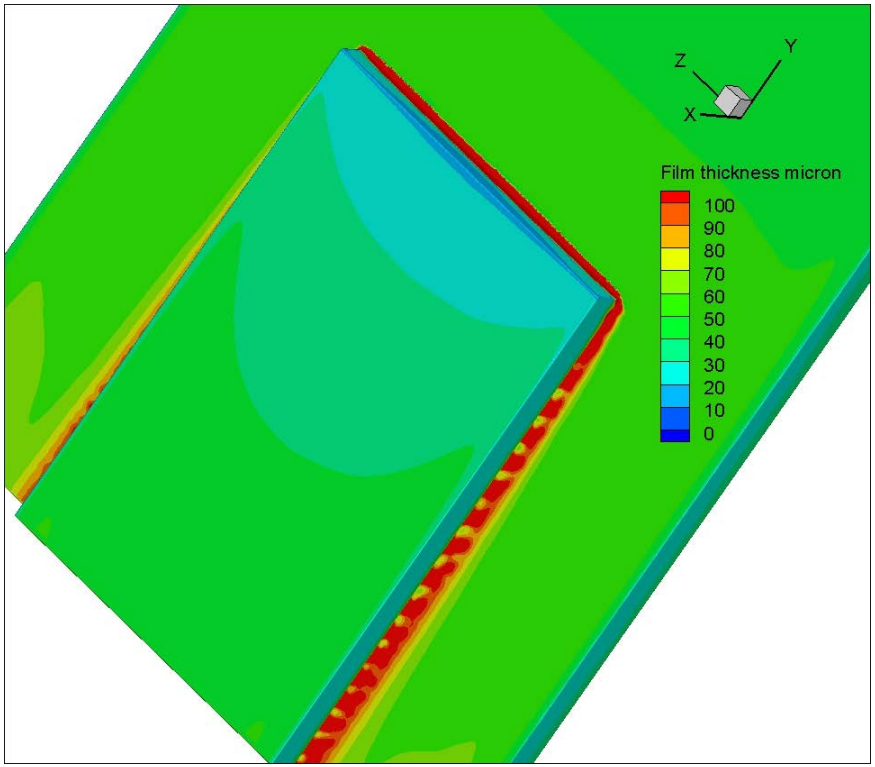
Model Predictions

Corrosion depth@28days (µm)



Film thickness



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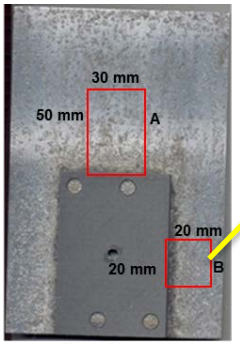
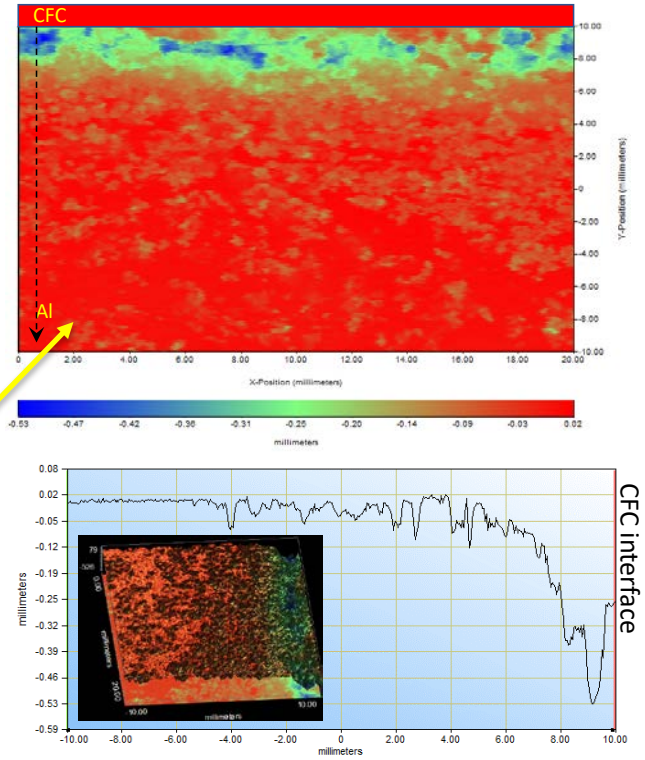
Results (3D Corrosion Depth Profiling)

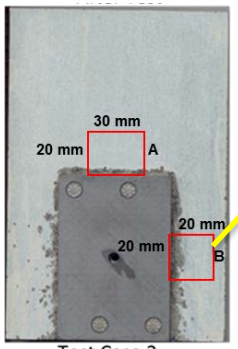
Al-7050 Bare



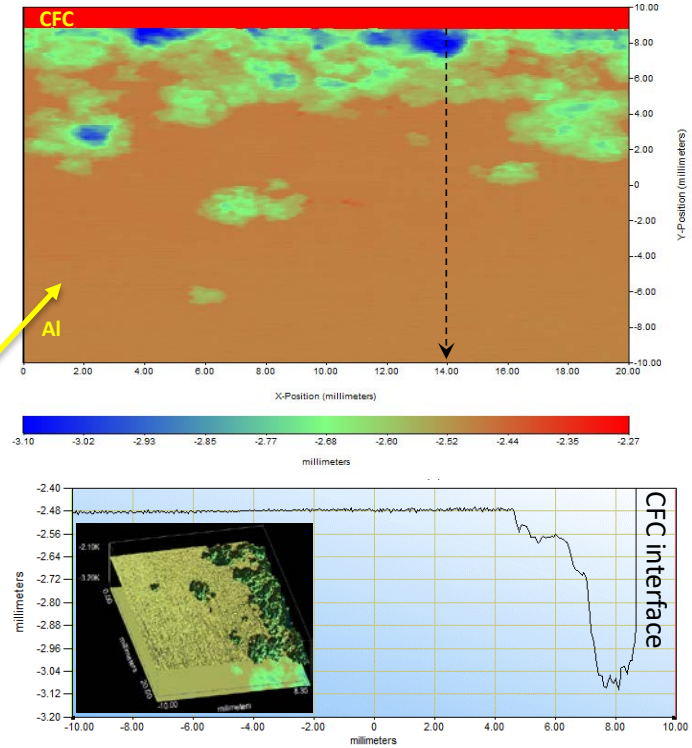
Test Case 1-
After Test



Al-7050 Anodized



Test Case 2-
After Test



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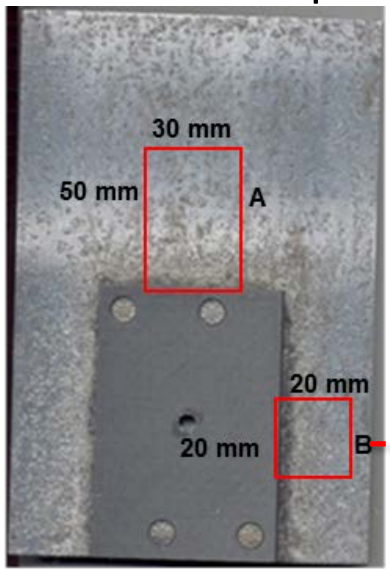
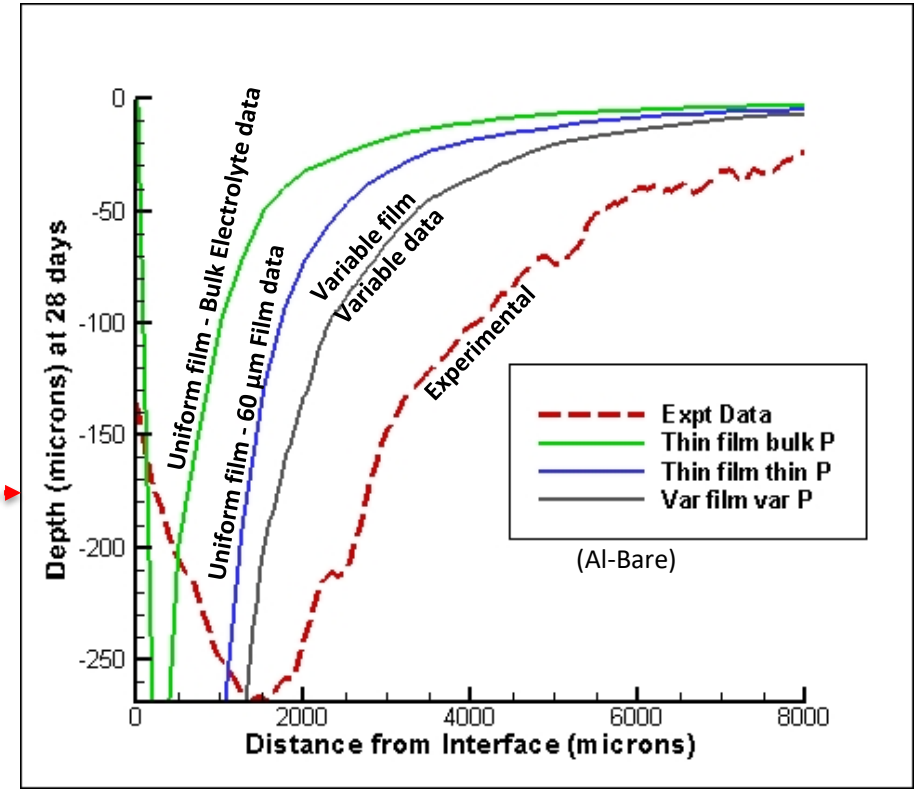
Experiment vs Model Predictions

Semi quantitative comparison:



Test Case 1-
After Test



(Al-Bare)

Total volume loss prediction compares well especially by accounting for variable film and the appropriate polarization curves

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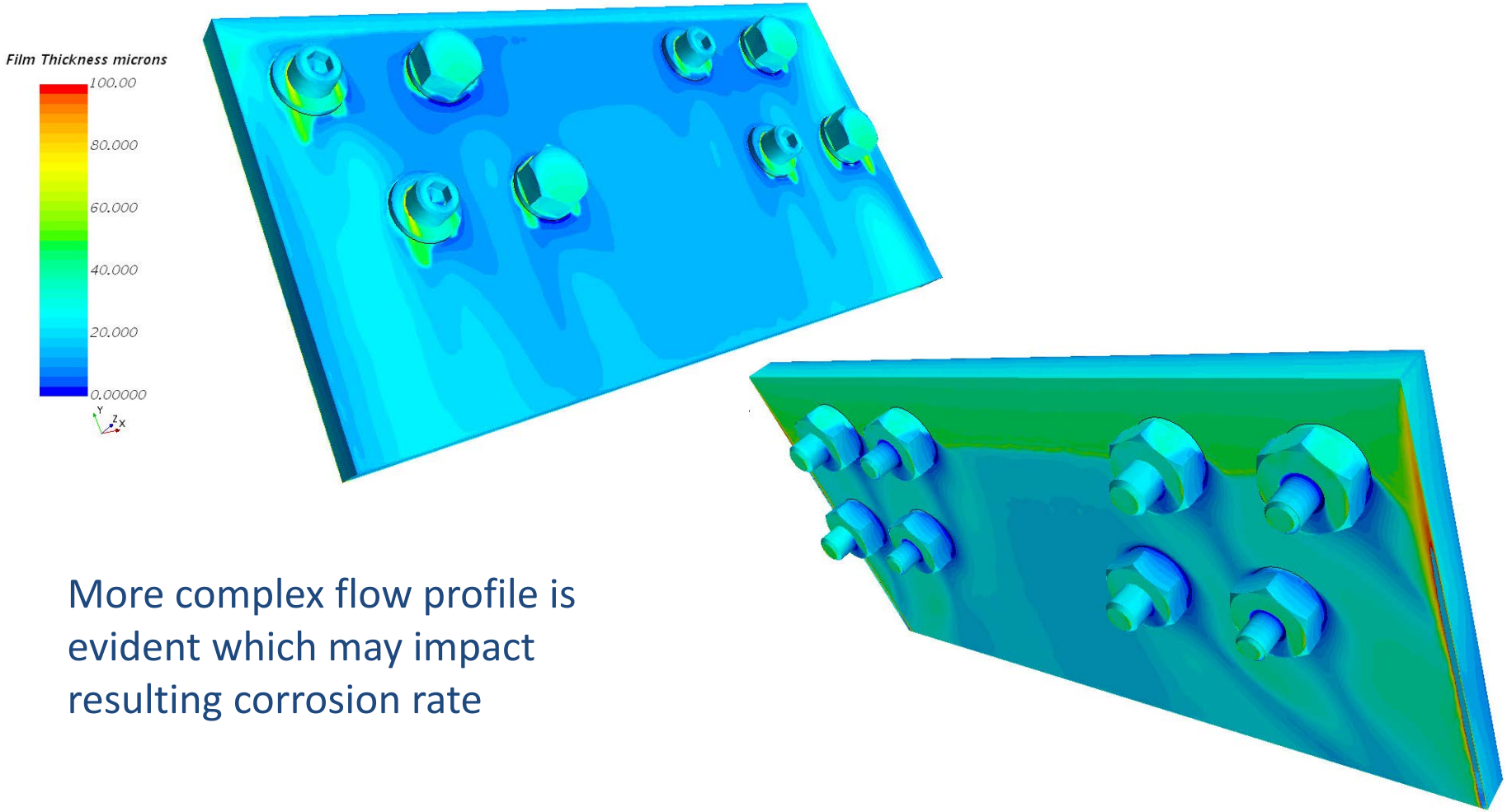
Fluid film profile on NAVAIR galvanic assembly



More complex flow profile is evident which may impact resulting corrosion rate

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Summary

Corrosion Djinn 3.1

- Easy to use and is gaining commercial traction amongst designers and M&P engineers
- Already in accordance with upcoming revisions of MIL-STD-889
- The key is DATA - consistent, robust, modern materials & coatings

3D CAE

- For complex geometries, film thickness distribution can impact the corrosion risk which we have been able to assess with a multiphase CFD approach

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Questions?

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