CORRDESA

Modeling and Simulation for the Finishing Industry

NASF SUR/FIN 2021

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CORROSION Djinn

Corrdesa Collaborators:
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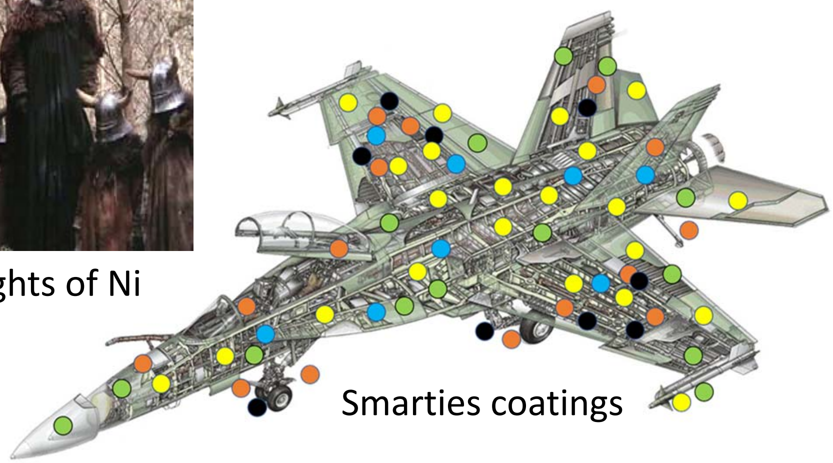
Agenda

- Introduction
- What are other industries doing?
- Surface Finishing is practical engineering – why use models when you’ve got the real thing?
- Electroplating – Plating Tool Design and Optimization
- Design of Coatings (metal filled etc)
- Coatings for Corrosion
- Quo vadimus?

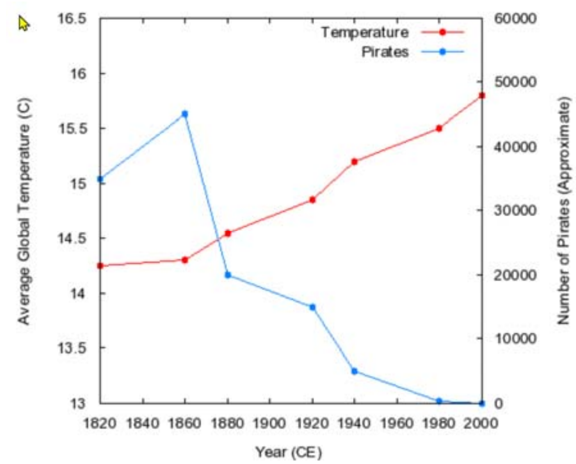
What should we discuss?

- When Jim Lindsay said that I could talk about anything, I thought Hmmm……………………

Nickel and the Knights of Ni



Smarties coatings



Influence of Pirates on Global Warming

We owe many of our businesses to this gentleman

- Michael Faraday
  - Laws of electrolysis, published 1834[1]
  - Many of our businesses depend on his work
  - As well as every cell phone in our pockets
  - 187 years later electrolytic coatings have penetrated almost every industry
- But as I have been watching the changes in industry over the past decade or so, I have seen modeling and simulation move from one industry to another, and it's our turn
  - **Seeing how and where it is used elsewhere, I think modeling could be more widely and profitably used in the Surface Finishing industry**

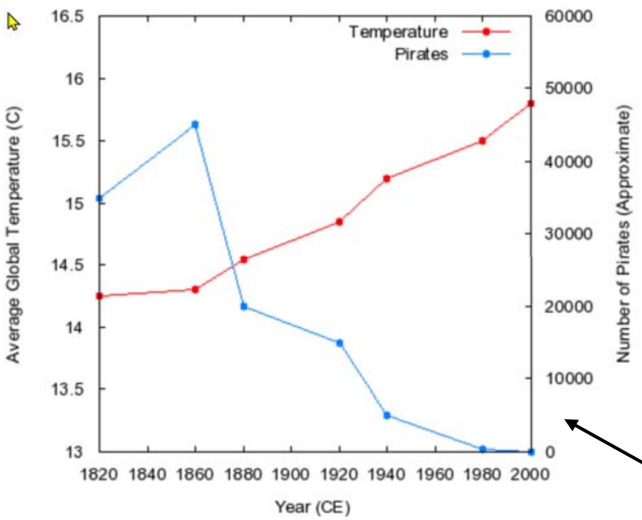
History of Science Museum
University of Oxford

1. Faraday, Michael "On Electrical Decomposition“, *Philosophical Transactions of the Royal Society*. **124**: 77–122 (1834)

It’s only a model

Models are not reality, but tools to make reality more comprehensible and predictable

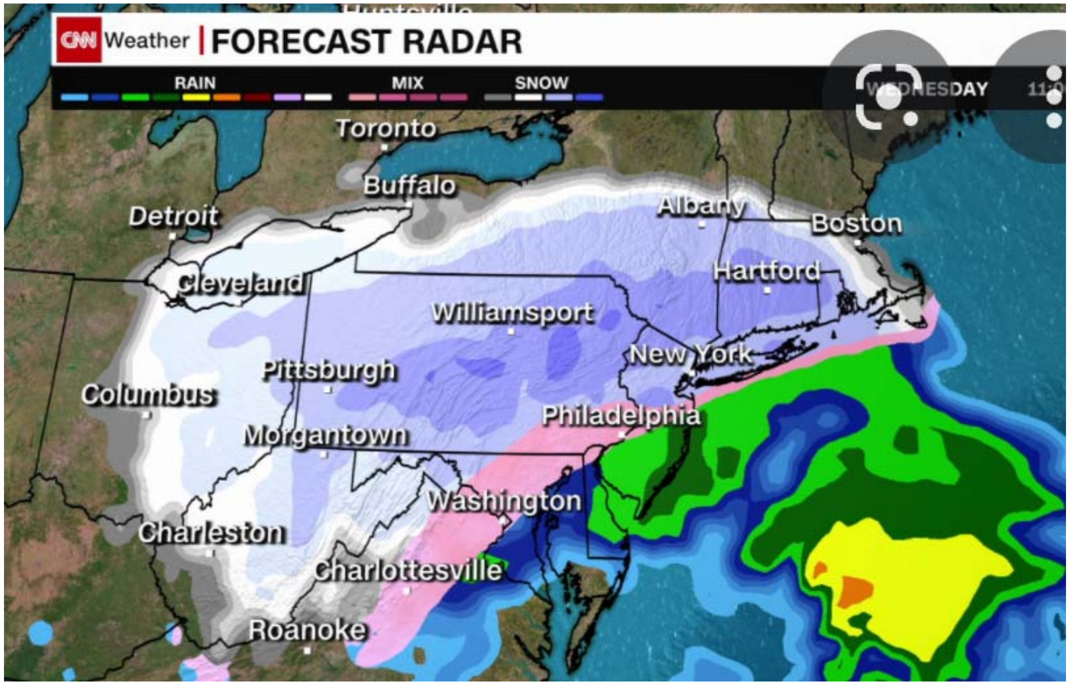
- Models give us a way to predict the behavior of complex systems, find ways to improve their performance, change the outcome



That's absurd. Anyone can see this correlates much better!

- Correlation is not causation!
- Just because it looks pretty and correlates or sounds convincing don't assume it is accurate or useful

We may not think about it, but we rely on modeling every day



From Trial & Error Design to Computational Design – Fluid Dynamics, Stress, Heat Transfer, Corrosion Modeling

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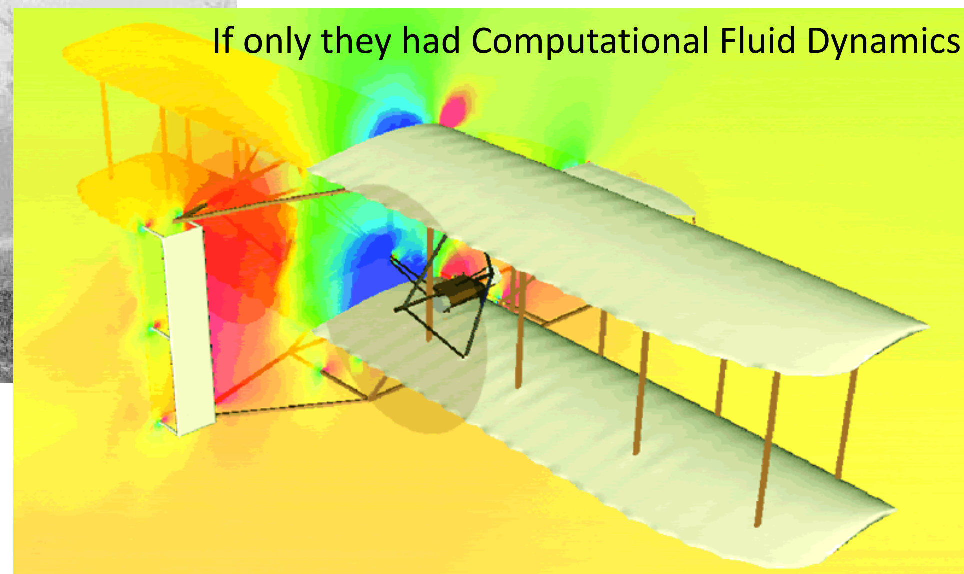
From concept to first flight Kitty Hawk, 17 December 1903, 5 years



Modeling can’t improve the weather but it can improve everyday appliances

- This type of modeling helps ensure that all surfaces will be properly washed
  - Adjust jet locations, spray spread, etc.
  - Minimize water usage

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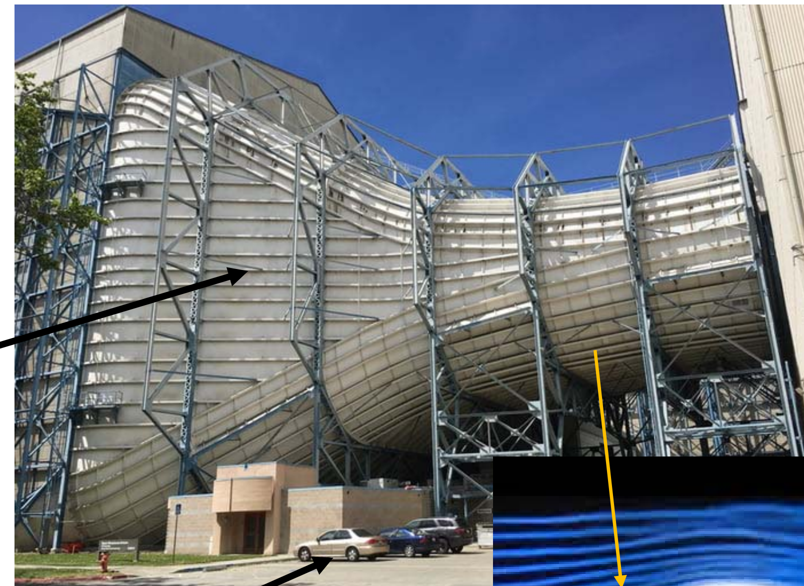
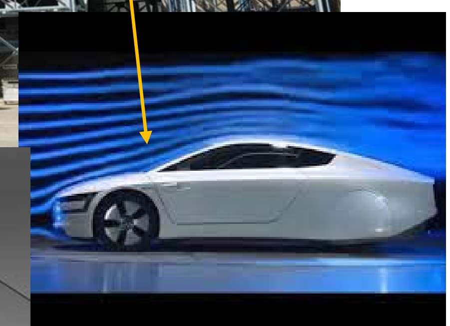
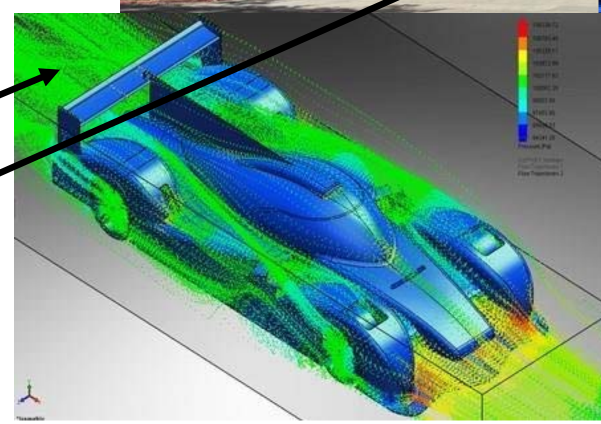
Fluid dynamics

- Fluid dynamics determines the forces on aircraft, cars
    - Visualize fluid flow
    - Measure lift, drag forces, etc
- We used to employ wind tunnels
    - Very expensive and limited quantitative data
- Now we use Computational Fluid Dynamics (CFD) modeling
    - The computer to do this fits in the trunk of this car
    - We also get a great deal more data

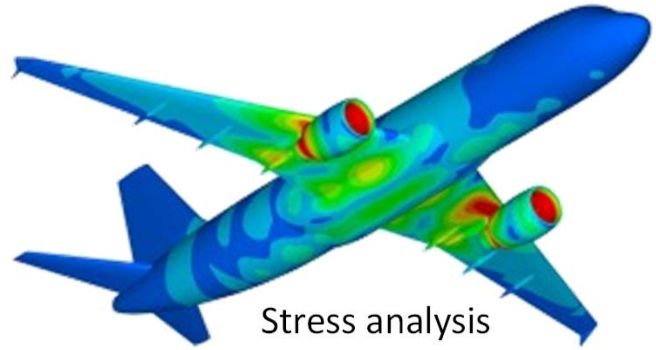




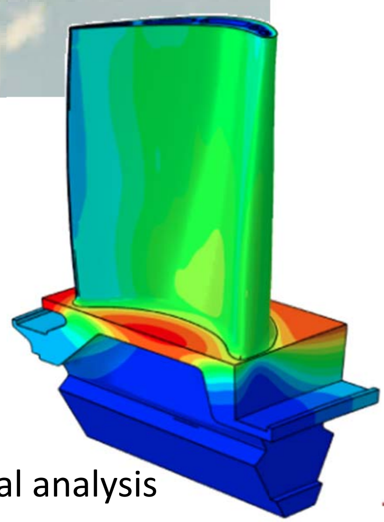


Modeling and modern design

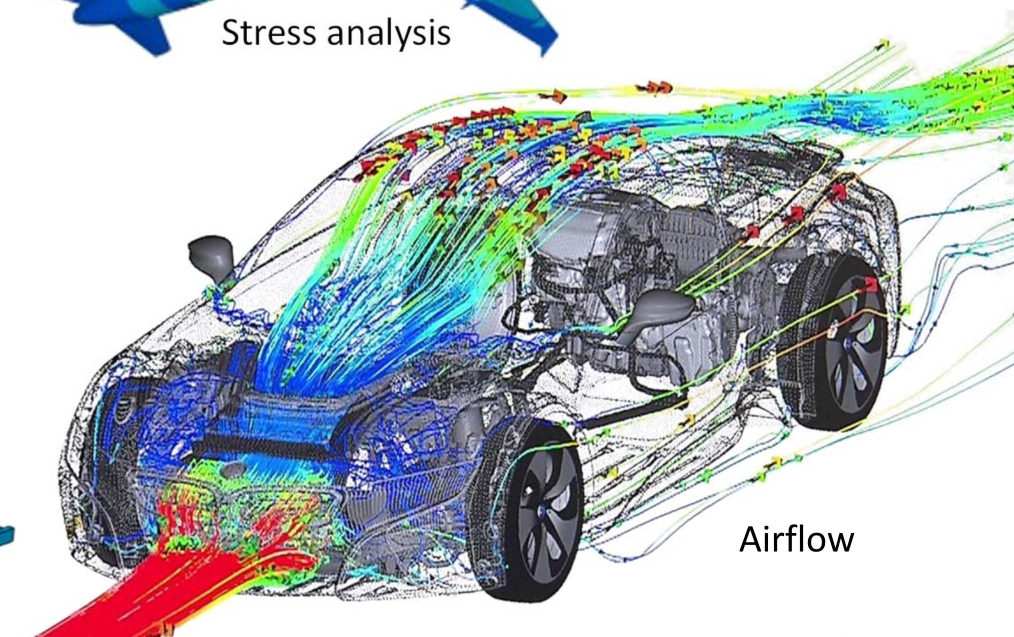
Computational fluid dynamics for airflow, stress analysis, thermal analysis



Stress analysis

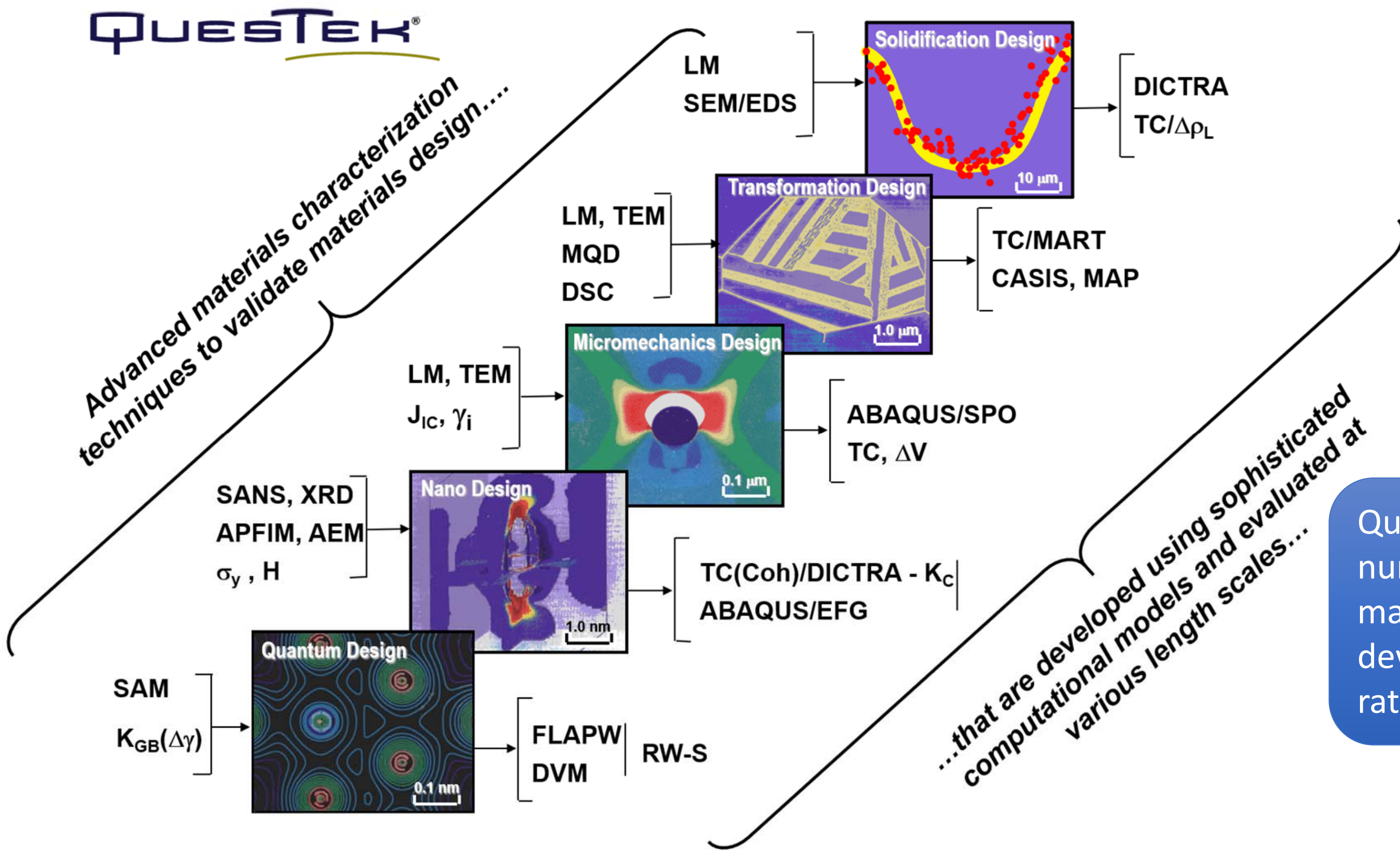


Thermal analysis



Airflow

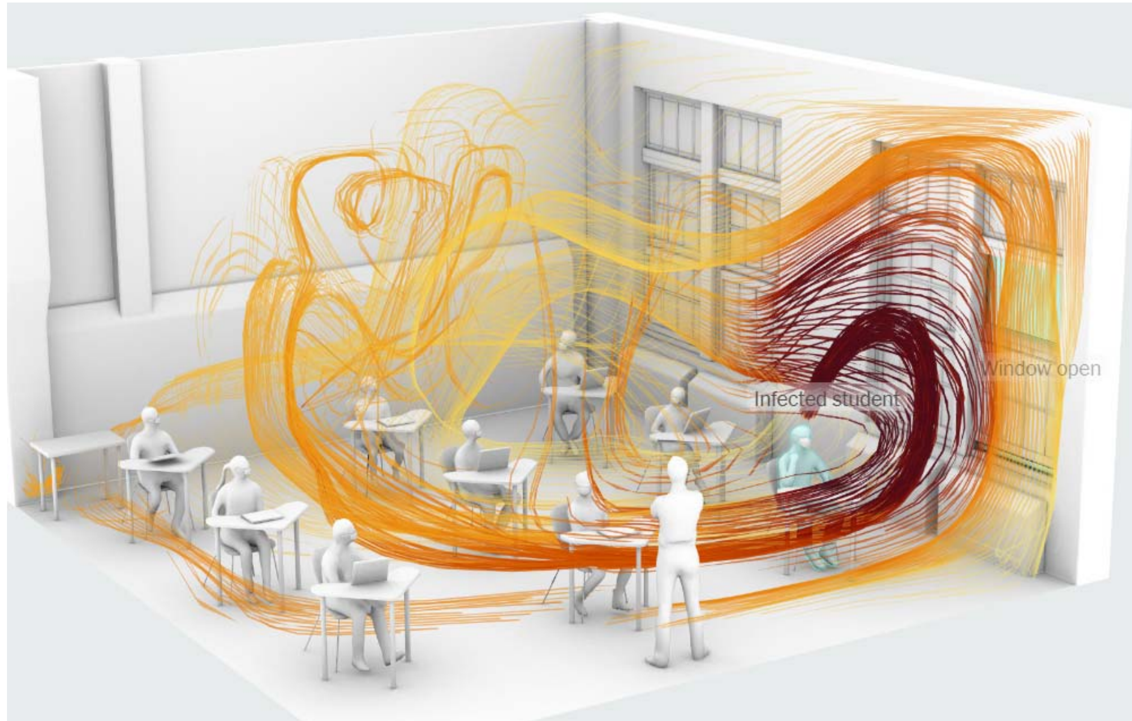
Computational Materials by Design



Questek Innovations uses numerous thermodynamic and materials modeling methods to develop new alloys in weeks rather than years

Computational Fluid Dynamics

- Now, with just an engineering workstation or a small high speed computer we can trace a sneeze
  - Follow the flow of gas and droplets
    - Something you cannot detect
  - Calculate densities, forces
    - Something you cannot measure
  - Quickly make changes to see the effect
    - Open a window, turn on a fan
    - Throw out that guy who is sneezing on everyone

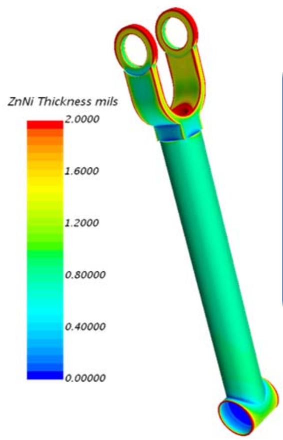


https://blogs.sw.siemens.com/simcenter/covid-19-and-cfd-simulation-with-siemens/

But a model is only as good as what goes into it

- A model must include all the critical processes
- It must have good quality data
- This does not mean it must be all-encompassing to be useful
  - But you need to know what its limitations are
  - Where it is valid and where it will break down
- E.g. If your product contains dissimilar materials a galvanic corrosion model may be fine
  - But if you have a lot of overlapping components you probably need a crevice corrosion model too
- If your product is used on a ship you need seawater corrosion data
  - But if it is used in a chemical plant you may need acid corrosion data

Corrosion model validation (B117)

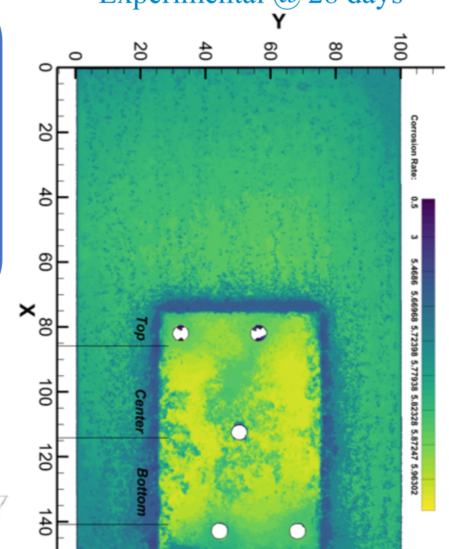


Before we apply modeling to complex systems we have to validate it on simple ones

Prove you can predict accurately for simple assembly

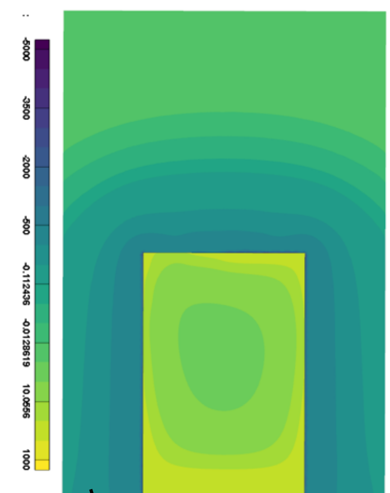
Carbon Fiber Composite (CFC)

Experimental @ 28 days



3D profilometer scan image (CFC plate removed)
Keyence VR3200 3D wide area macroscope

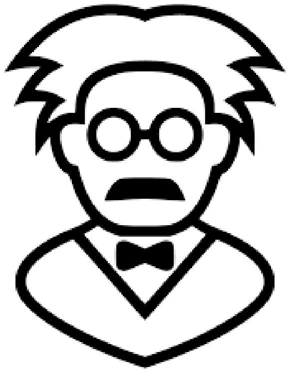
CFD @ 28 days



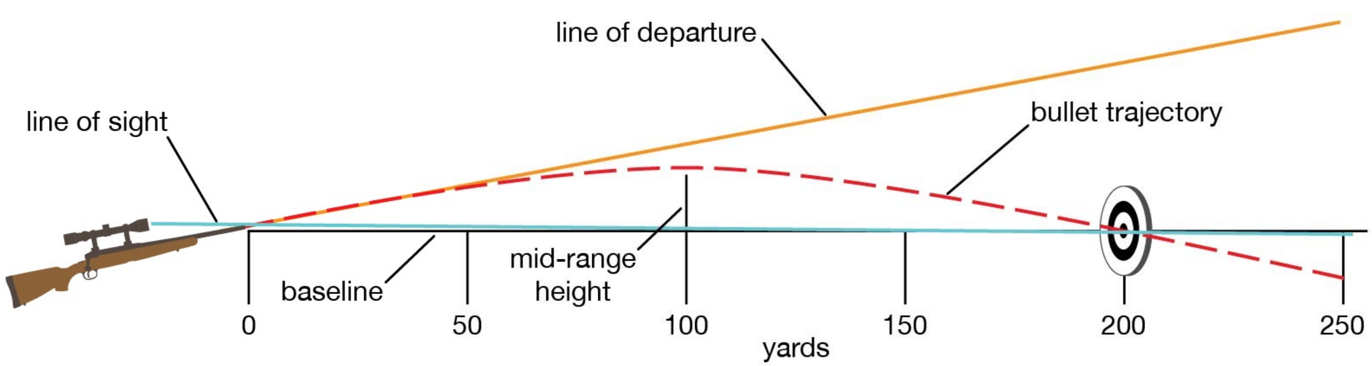
Corrosion depth (CFD)

	Total volume loss (mm^3)	
	Measured (Experimental)	Model
Al7050-T7451 (Bare)	239	261

In physics everything is more or less a straight line



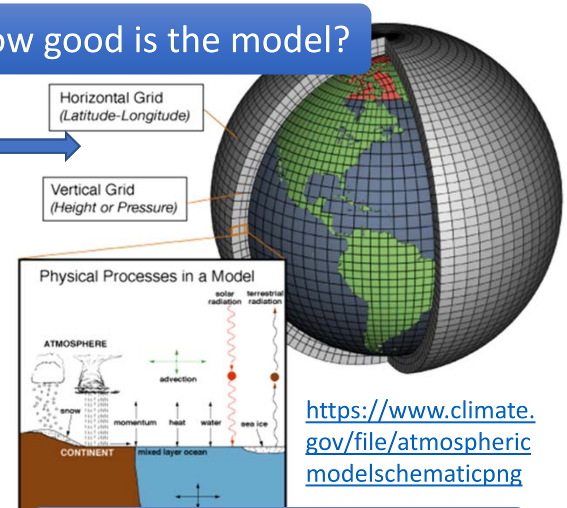
- Well, it is a straight line if you only predict over a short distance or a short time
  - What matters is predicting where the bullet lands
- Prediction is only useful if it works over a dimension (distance/time, etc) that is relevant to your problem



How do you know that a model is any good and whether or not it is useful to you?

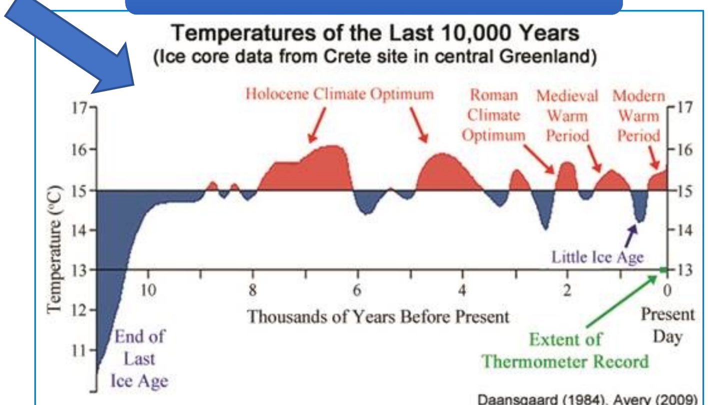
- Complex systems must accurately include all critical variables
  - E.g. Climate models are extremely complex and hard to validate
- A model may look impressive but is it **validated**?
  - Is it validated against well-defined, accurate data?
    - No direct temperature measurements - Ice cores, tree rings are <u>proxies</u>
    - When you use a proxy you must ensure it is valid and accurate
  - Does it **hindcast**?
    - Does it predict known data – e.g. ice ages, major warmings/coolings?
    - Is it possible to identify/measure/model all the critical drivers?
      - If we cannot, how does that restrict the range of model validity?
- How accurate must the model be to get useful answers?
  - Must it be accurate and absolute, or rough and relative?
  - Must it forecast short term or long term? Decades or millenia?
  - What are the consequences of a wrong answer?

How good is the model?



https://www.climate.gov/file/atmosphericmodelschematicpng

How is the model validated?

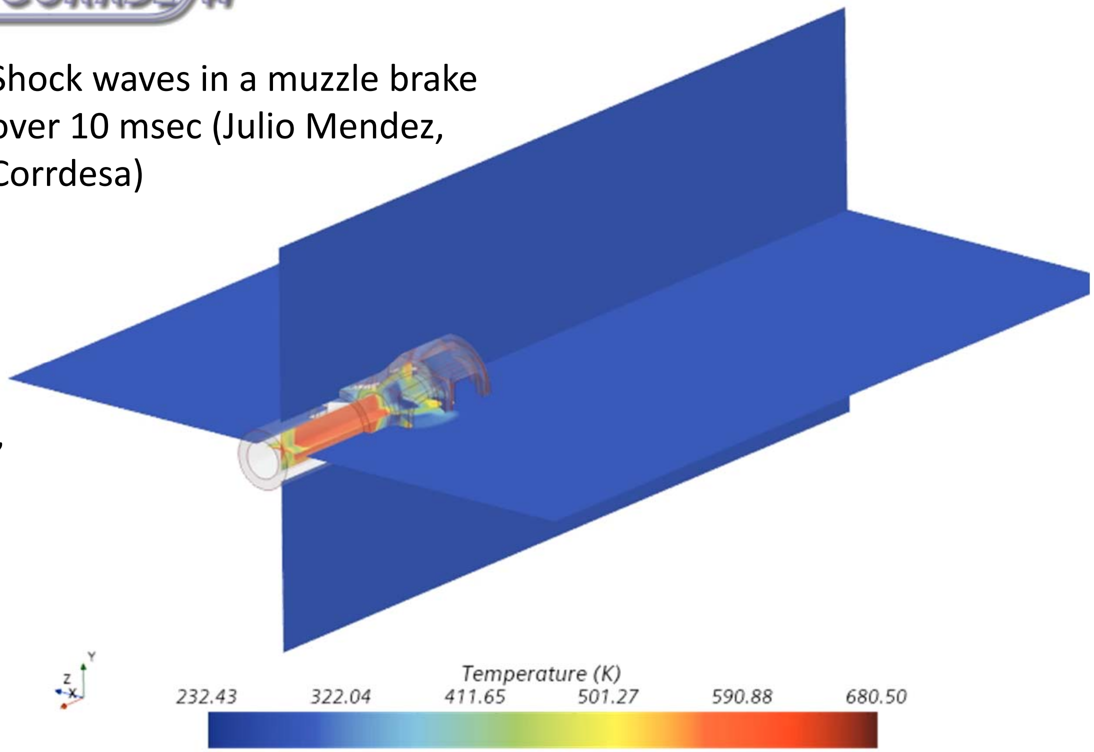


How accurate is the validation data?

But what if you can't measure anything directly?

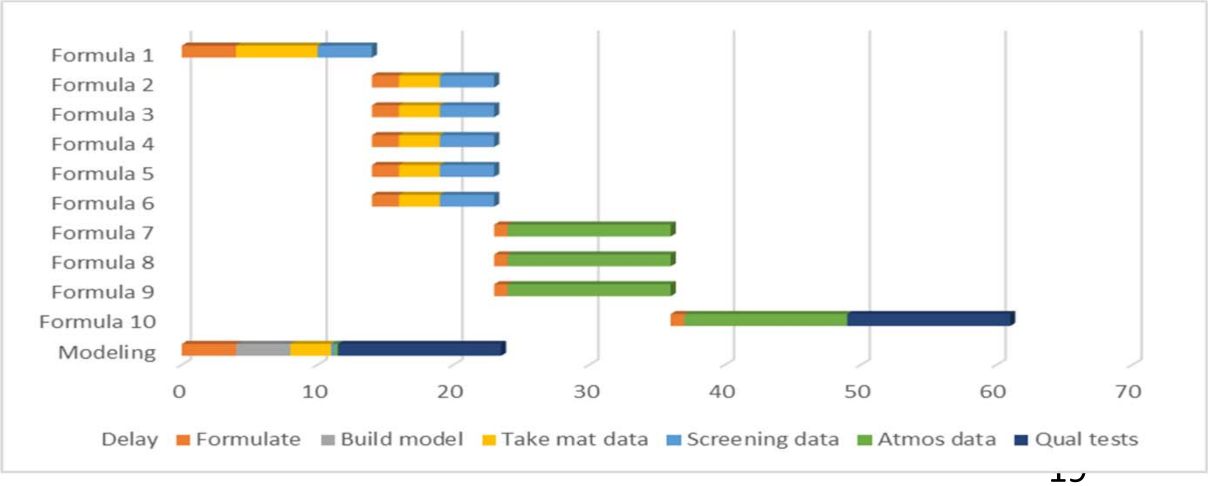
- Modeling eliminates making/testing numerous designs. To design a muzzle brake to reduce gun recoil you need to know velocities, temperatures, pressures **inside** the barrel as the projectile leaves the muzzle
  - There is no way to measure all that so you have to model it. That means you must use a model based on correct physical/chemical principles
  - Validation: Predict proxy values you can measure
    - Projectile velocity, recoil forces
    - Particle/gas temperatures and velocities at vents

Shock waves in a muzzle brake over 10 msec (Julio Mendez, Corrdesa)



What is the most important thing that modeling does for you?

- Gives you the insight to improve processes and handle change efficiently, with a lot more certainty
- It is almost always far faster and cheaper to develop and optimize materials and processes using modeling than using formulation and testing
  - Particularly important for developing and optimizing coatings
- Why?
  - Formulation is only the beginning
  - Then there is
    - Multiple re-formulation
    - Screening tests
    - Downselect
    - Atmospheric tests
    - Component tests
    - Qualification tests
    - Finally (if you did it right)
      - Authorization and production



When your product or process has to change……

- You need to redesign a component
  - A model lets you quickly check how you will affect system performance
- REACH bans yet another of your critical chemicals or coatings
  - First you have to get the materials data from the alternatives
  - Then you can quickly rerun your models with all the alternatives to see how performance changes. Cr6 > Cr3 > non-Cr
- You want to enter a new market
  - You can model performance directly over the entire product for all manner of stresses and environments
- Customers want to use your products in new applications
  - You can reduce risk by evaluating any number of what-ifs – far more than you could possibly test
  - This includes checking for possible but unusual scenarios that would not happen in normal service testing – or that would be disastrous if they did

Example: Automotive component plating

Ford and GM both encourage or require computational modeling to ensure coating thickness uniformity on PoP parts

GMW14668 spec:

> 3.3.1 Plating Thickness. Minimum plate thickness……(for chrome) applies to all significant surfaces.
>
> 3.3.1.1 Computer Aided Engineering (CAE) plating thickness simulations are recommended when there is uncertainty of meeting minimum plating thicknesses due to part design features.

Some companies always carry out computational modeling whether the customer requires it or not

- Meet specs for thickness uniformity across components and across the rack
- Optimize the loading on the rack for maximum throughput consistent with coating quality

Some companies that design, mold and plate also use CFD to optimize mold filling, ensure part quality, plateability and plating quality

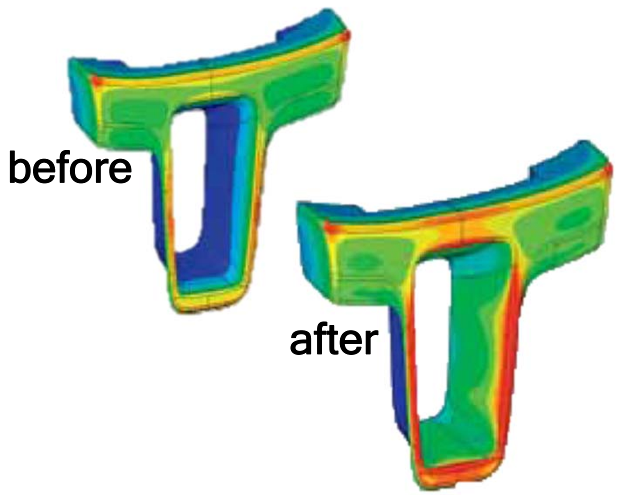
Automotive component plating (Siemens)

Plating Metal on Plastic

Easy to plate:
-Flat
-Large openings

Difficult to plate:
-Recessed areas
-Large openings

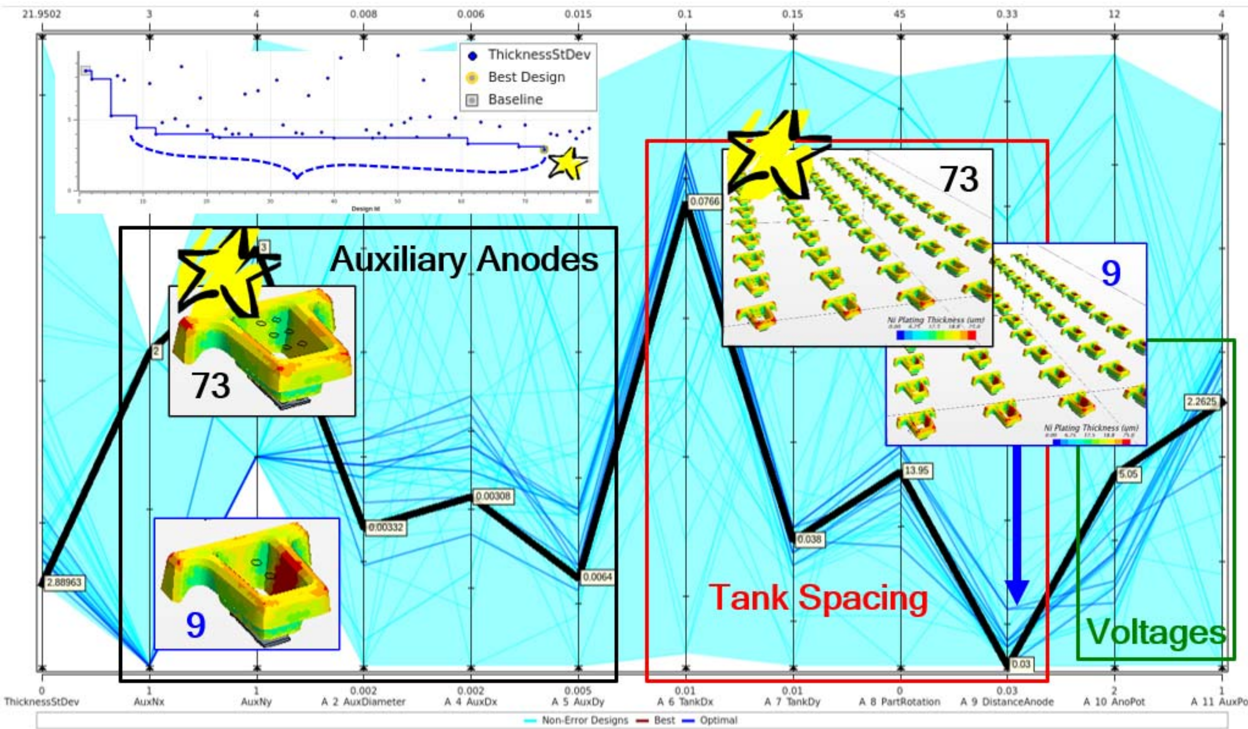
TRW 2012: Literature highlights the importance of auxiliary anodes1

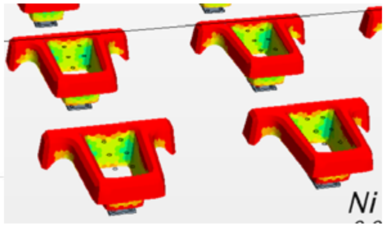


1.- "Introduction of Auxiliary Anode Technology for Production of Highly Decorated Chromium-Plated Steering-Wheel Bezels at TRW"
Von Gerd Reineck, Galvanotechnik 2012

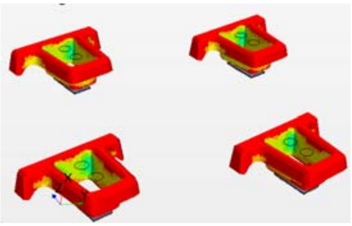
Automotive component plating (Siemens)

Objective: Minimize Thickness Standard Deviation
Design Variables: Rotation, Spacing, Anode Standoff, Anode Voltage, diameter of auxiliary Anodes, orientation of auxiliary Anodes, Voltage of auxiliary Anodes.

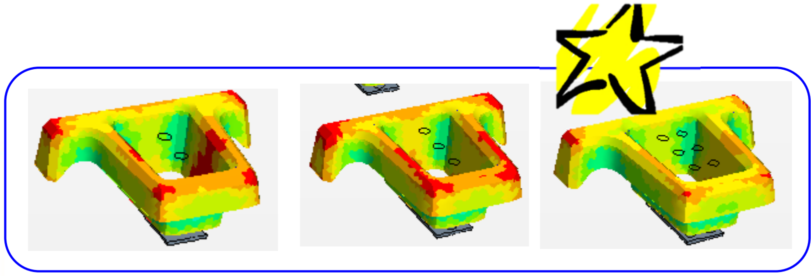




Orientation of auxiliary Anodes



Diameter of auxiliary Anodes



Best Designs

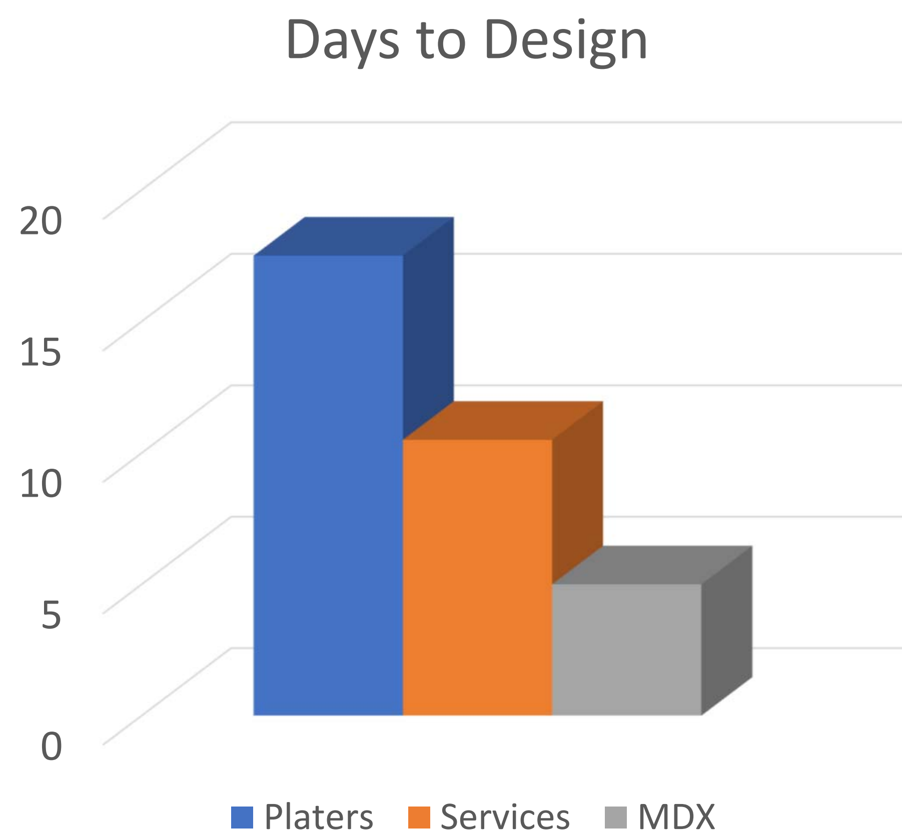
Imagine how long this would take if you had to do tank runs. “Something that works best” rather than just “something that works”

Automotive component plating (Siemens)

Plating Shops build and test
- 6 - 7 designs
- 2 - 3 weeks

Service Engineers digital test
- 10 - 20 designs
- 1 - 1 weeks

Multidisciplinary Design Exploration (MDX) (Optimization)
- 80 designs
- Setup 2-5 days
- Run 1.5 days (desktop w/ 12 cores)



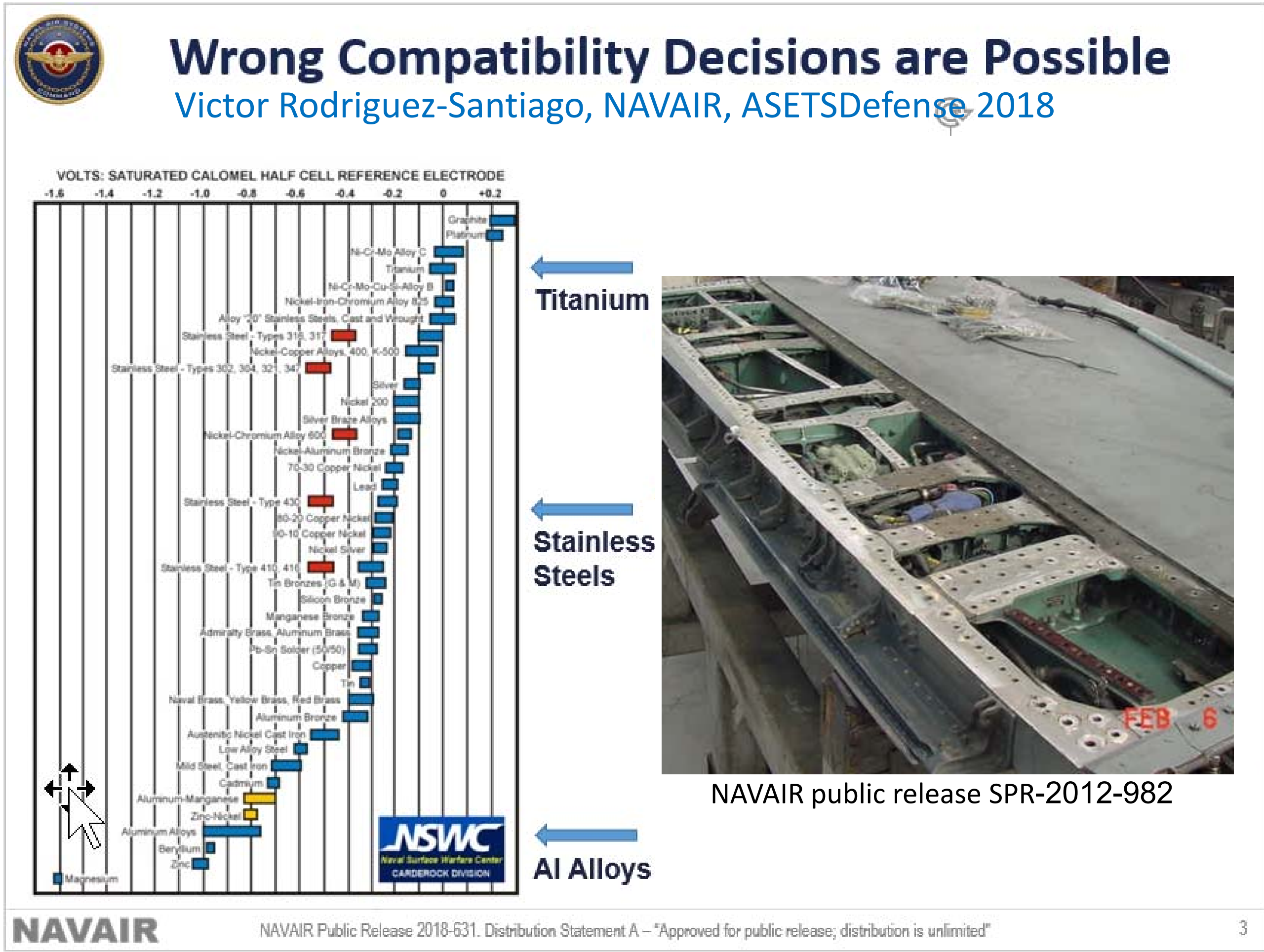
And when something in the design is changed you can rerun the optimization very quickly

Why use modeling in surface finishing and corrosion?

- Stress engineers, heat transfer engineers, vibration engineers all have models with pretty pictures showing why their solutions will work
- The poor corrosion/coatings engineer cannot prove (even to himself) that his solution will work
  - He can only say “Trust me, I’m a corrosion expert”
- Without quantitative modeling the Corrosion/Coatings Engineer feels he is bringing a knife to a gunfight

Models don't have to be complicated to be useful, but they do have to be right

- NAVAIR briefing on MIL-STD-MIL-STD-889D: Victor Rodriguez-Santiago, ASETSDefense Workshop 2018
    - "Galvanic Compatibility Assessment: New Methodology and Standardization"
- **MIL-STD-889D issued July 2021**



Corrosion modeling – MIL-STD-889D

Getting it right means you must define the way the model is made, where it is valid, and how to take the data that go into it

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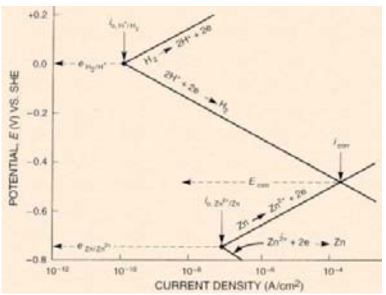
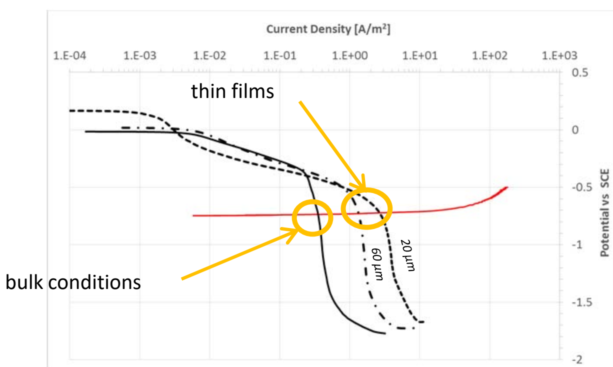
1D 2D 3D

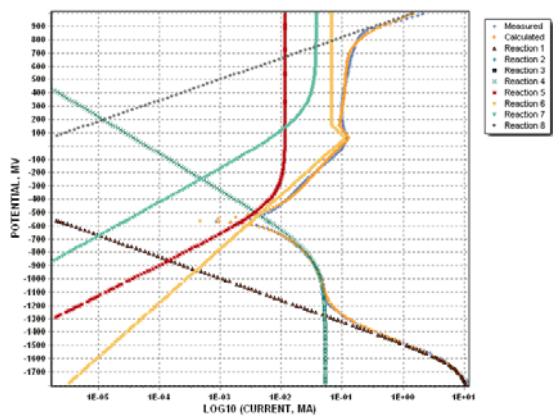
Accuracy-Cost



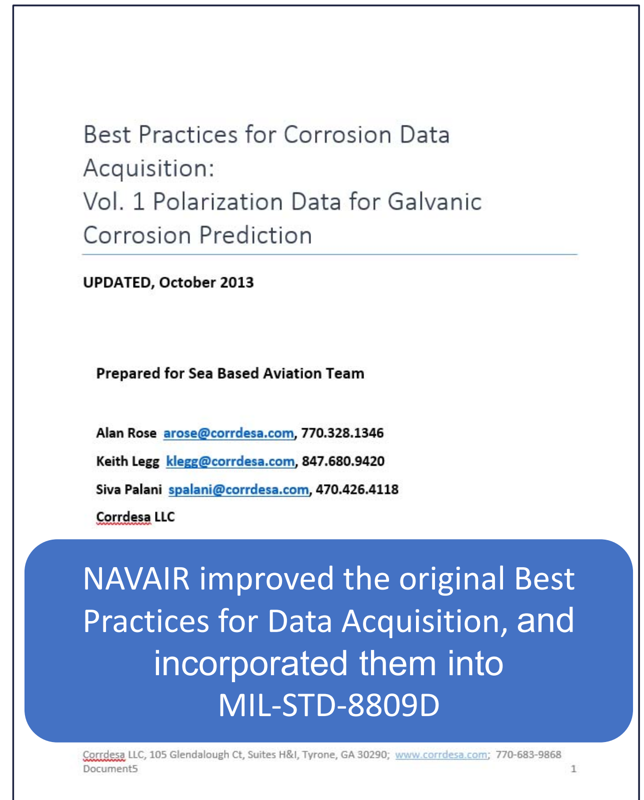
Mixed potential principle (Conservation of charge)



Mixed potential principle + electrodynamic potential



Mixed potential principle (deconvoluted) + electrodynamic potential + Navier Stokes Equations



Best Practices for Corrosion Data Acquisition:
Vol. 1 Polarization Data for Galvanic Corrosion Prediction

UPDATED, October 2013

Prepared for Sea Based Aviation Team

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Document5 1

NAVAIR improved the original Best Practices for Data Acquisition, and incorporated them into MIL-STD-8809D

New Mil-STD-889D issued July 2021: Adios to the Galvanic Chart

TABLE I. Galvanic compatibility of bare conductive materials in a 1:1 A/C in immersed artificial seawater.

Anodic Material \ Cathodic Material	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
1. Mg EV31		5	6	6	6	6	6	6	6	5	6	6	6	6	6	6	6	6	6	6	6	6	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
2. Mg WE43			6	6	6	6	6	6	6	5	6	6	6	6	6	6	6	6	6	6	6	6	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
3. Mg AZ31B				5	6	6	6	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
4. Zinc					5	3	5	3	4	3	5	5	5	6	6	3	6	5	6	5	5	4	4	5	5	5	5	5	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3	6	6
5. Zn-Ni Plated						3	5	3	4	4	5	5	5	5	5	4	5	5	5	5	4	4	4	5	5	5	5	5	6	4	5	5	5	5	5	5	5	5	5	5	5	4	5	4	4	5	6
6. Al5083							3	2	2	2	3	4	5	5	5	2	4	3	4	3	2	3	2	4	4	4	4	4	5	3	5	4	4	3	3	4	5	4	3	4	4	3	4	3	3	5	5
7. Cadmium								4	5	4	5	5	5	5	5	4	5	5	5	5	5	5	4	5	5	5	5	5	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	6	5
8. Al6061									2	2	3	4	5	5	5	2	4	3	4	3	2	3	2	4	4	4	4	4	5	3	5	4	4	3	3	4	5	4	3	4	4	3	4	3	3	5	5
9. CP Aluminum										2	3	4	5	5	5	2	4	3	4	3	2	3	2	4	4	4	4	4	5	3	5	4	4	3	3	4	5	4	3	4	4	3	4	3	3	5	5
10. A356											3	4	5	5	5	2	4	3	4	3	2	3	2	4	4	4	4	4	4	3	5	4	4	3	3	4	5	4	3	4	4	3	4	3	3	5	4
11. 1020 Steel												4	5	5	5	3	4	4	4	4	3	3	3	4	4	4	4	4	5	3	4	4	4	3	3	4	4	4	3	4	4	3	4	3	3	5	4
12. Al7075													5	5	5	4	5	5	5	5	4	5	4	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5	5	4	5	5
13. A36 Steel														5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
14. 1018 Steel															5	4	5	5	5	5	4	5	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
15. 1008 Steel																5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
16. Al7050																	4	3	4	3	2	3	2	4	4	4	4	4	5	3	5	4	4	3	3	5	5	4	3	4	4	3	4	3	3	5	5
17. B7 Steel																		4	4	4	3	4	3	4	4	4	4	4	5	4	4	4	4	3	4	4	5	4	4	4	4	4	4	4	3	5	4
18. MIL-11356 Steel																			4	3	3	3	3	4	4	3	3	4	4	3	4	4	4	3	3	4	4	4	3	3	4	3	3	3	3	5	4
19. 4340 Steel																				4	3	3	3	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4	3	4	4	4	4	4	3	5	4
20. HY80 Steel																					3	3	3	4	4	4	4	4	4	3	4	4	4	3	4	4	4	4	3	4	4	4	4	4	3	5	4
21. Tin																						3	1	4	4	4	4	4	2	3	3	3	3	2	2	3	3	3	2	3	3	3	3	2	3	5	5
22. Al2024																							3	4	4	4	4	4	3	3	5	4	4	3	4	4	5	4	3	4	4	4	4	3	3	5	5
23. Ti-6Al-4V																								3	2	3	2	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
24. Brass, Yellow																									4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	5
25. Bronze																										3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4
26. NiAl, C630																											3	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	5
27. CuBe																												3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4
28. CP Copper																													3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4
29. PH 13-8																														0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
30. 304SS																															0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
31. PH 15-5																																0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
32. 304SS Passivated																																	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
33. 410SS																																		0	0	0	0	0	0	0	0	0	0	0	0	0	1
34. Inconel* 600																																			0	0	0	0	00	0	0	0	0	0	0	1	1
35. A286 Passivated																																				0	0	0	0	0	0	0	0	0	0	0	1
36. PH 17-4																																					0	0	0	0	0	0	0	0	0	0	1
37. 316SS																																						0	0	0	0	0	0	0	0	0	1
38. 316SS Passivated																																							0	0	0	0	0	0	0	0	1
39. Monel* 400																																								0	0	0	0	0	0	1	1
40. 410SS Passivated																																									0	0	0	0	0	0	1
41. A286																																										0	0	0	0	0	1
42. PH 17-4 Passivated																																											0	0	0	0	1
43. PH 13-8 Passivated																																												0	0	0	1
44. PH 15-5 Passivated																																													0	0	0
45. Silver																																														1	3
46. Graphite																																															1

Al 7075

Al 7050

Al 2024

3

3

4

Ti6Al4V

PH13-8 passivated

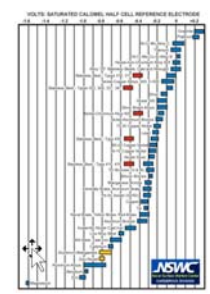
PH13-8 bare

MIL-STD-889D

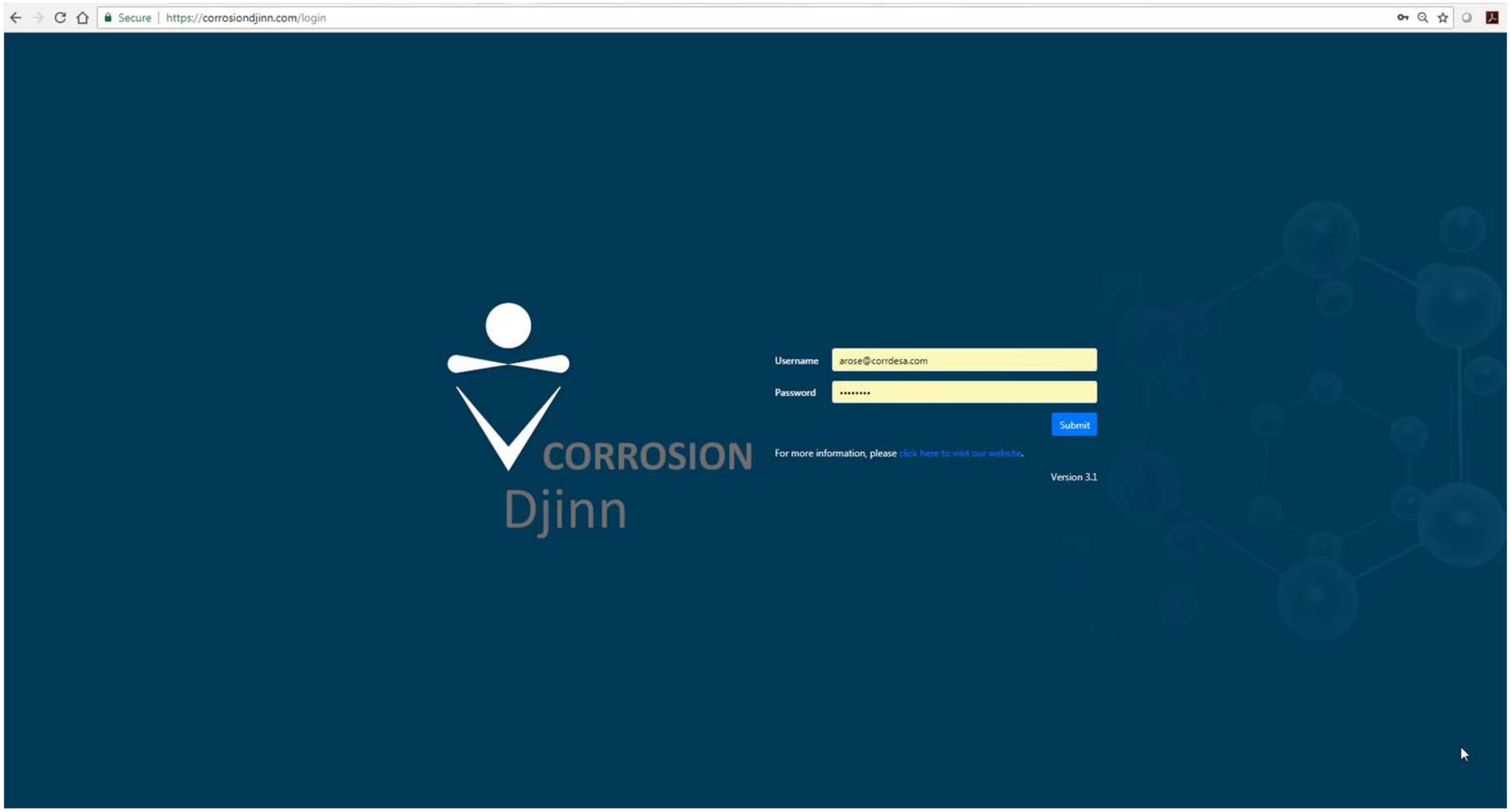
Galvanic corrosion rate at interface between two equal areas:

0. <0.09 mil/year
1: 0.01-0.09 mil/year
2: 0.1-0.9 mil/year
3: 1-4.99 mil/year
4: 5-9.99 mil/year
5: 10-99.99 mil/year
6: > 100 mil/year

It may not be as pretty, but it's right



Corrosion Djinn® Quick Demo



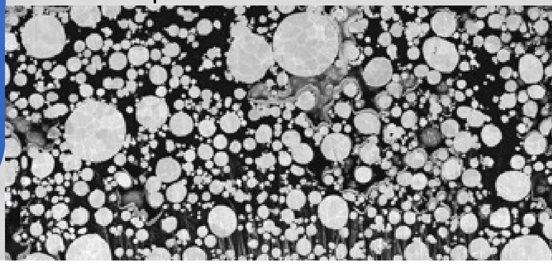
www.corrosiondjinn.com

Its so easy even the boss can do it

Example: Al-rich primer for wet-install

- The problem:
  - Naval aircraft operate off aircraft carriers – the world's most corrosive environment
- Today's solution: Cd plate and wet-install every bushing and fastener
  - Dip them in primer before installing to keep water out of the galvanic interfaces
  - But only some depots can Cd plate and Ti is difficult to machine
  - So they often machine stainless steel bushings – with predictable results

NAVAIR public release SPR-2012-982



Possible solution: Wet install with sacrificial Al-rich primer

But how can you optimize a primer with so many variables?

Pigment material/size/shape/loading/treatment

Polymer material/porosity/electrolyte content/impedance

Component dimensions/material/coating/ treatment

Bushing material/coating/treatment

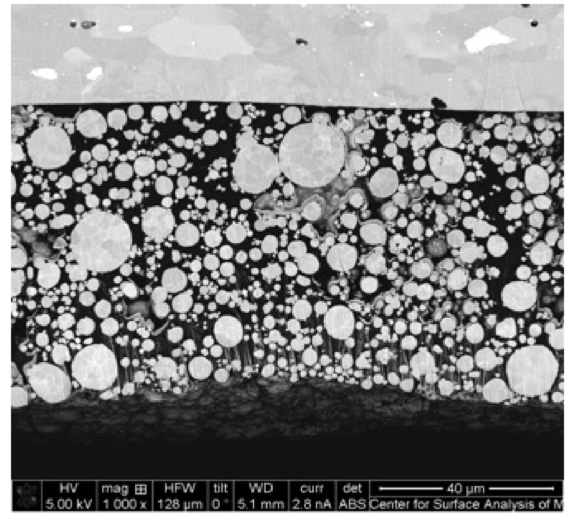
Environment NaCl loading/time of wetness/deliquescence/film thickness…..

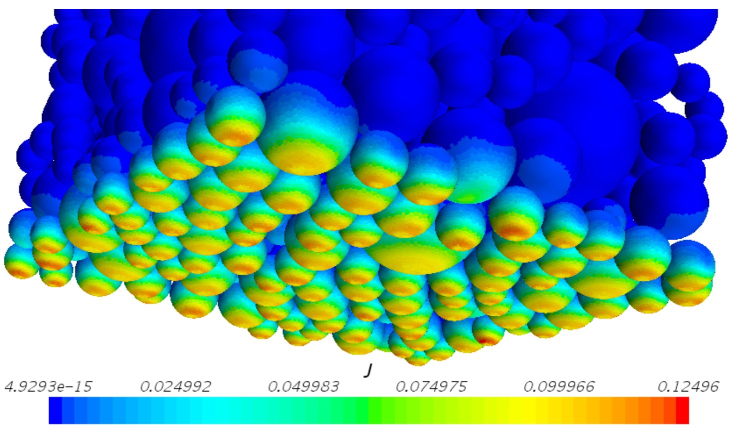
Need hundreds of formulations, thousands of tests, millions of $$

We cannot afford to find 2,000 ways **not** to make a light bulb

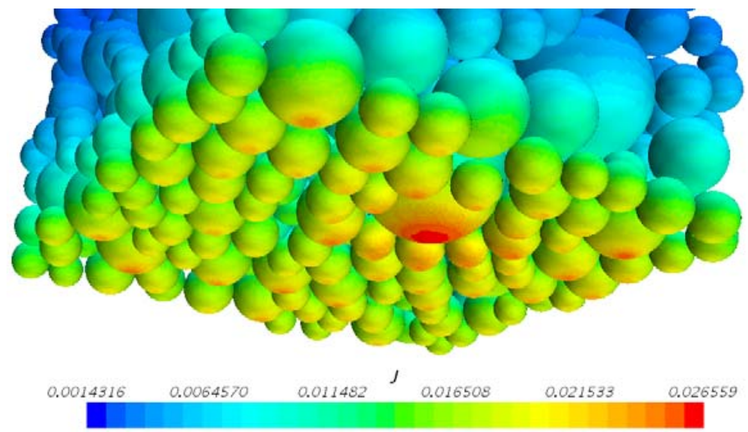
Al-rich primer for action and wet-install

- Can modeling be used to optimize something this complicated and this small?
- Particle electrochemistry, shape and size distribution determine electrochemical performance
- But when you model it you find the most important issue is the impedance of the polymer
- You can calculate the optimum pigments and polymers
- But can you make it?





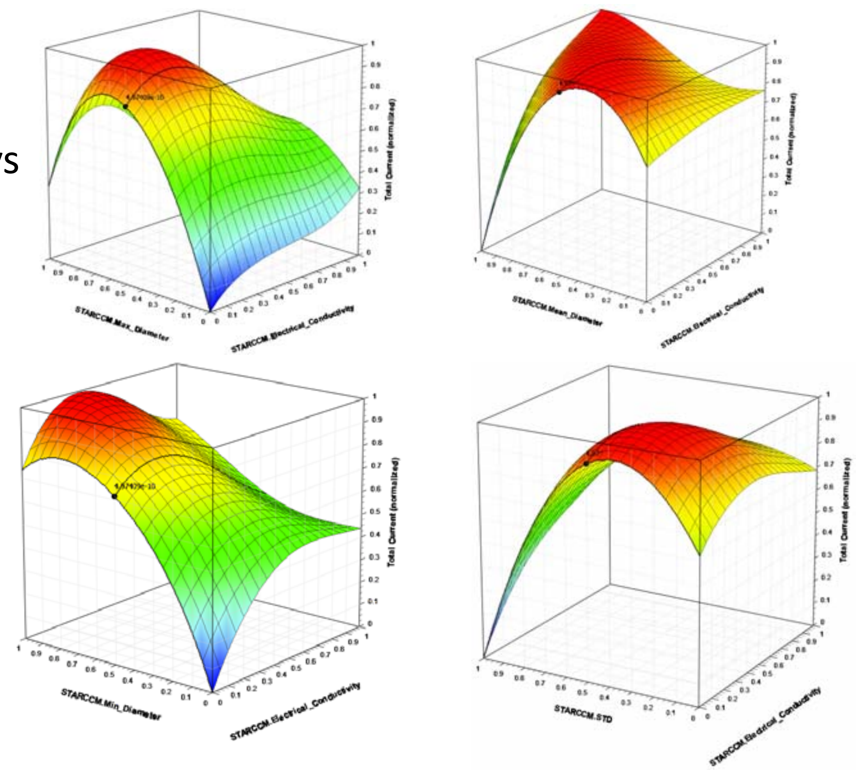
High impedance: Very localized and high current density concentration



Low impedance: More uniform distribution as more particles are active due to low ohmic resistance in the polymer

Modeling: Al-rich primer for wet-install

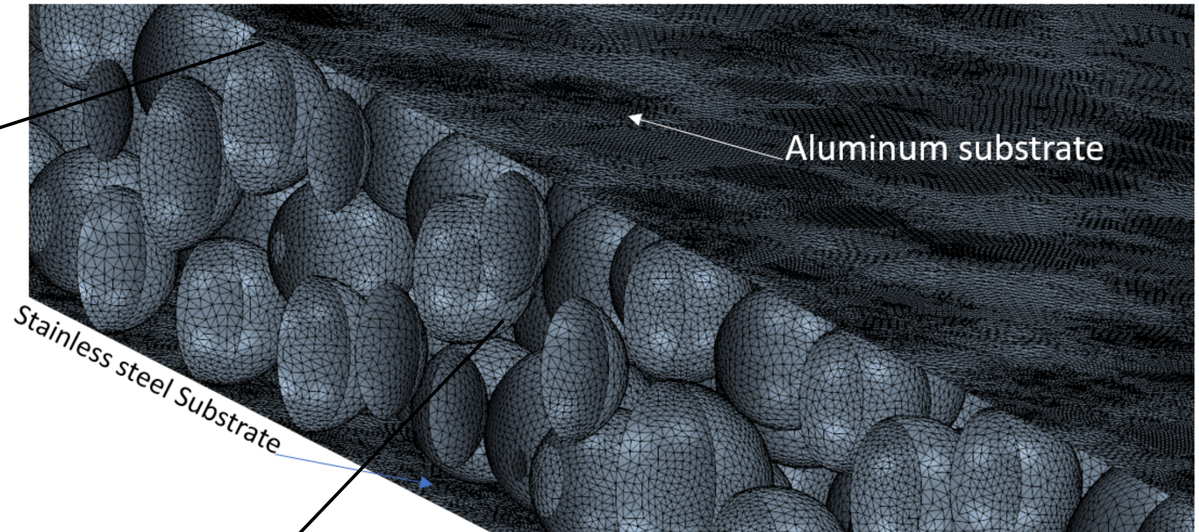
- Took a couple of years to develop the model and measure underlying electrochemical properties of its constituents
- Once model developed CFD workflow automation took days instead of weeks. Optimization took thousands of simulations over a few weeks.
- Result – Optimum formulation defined

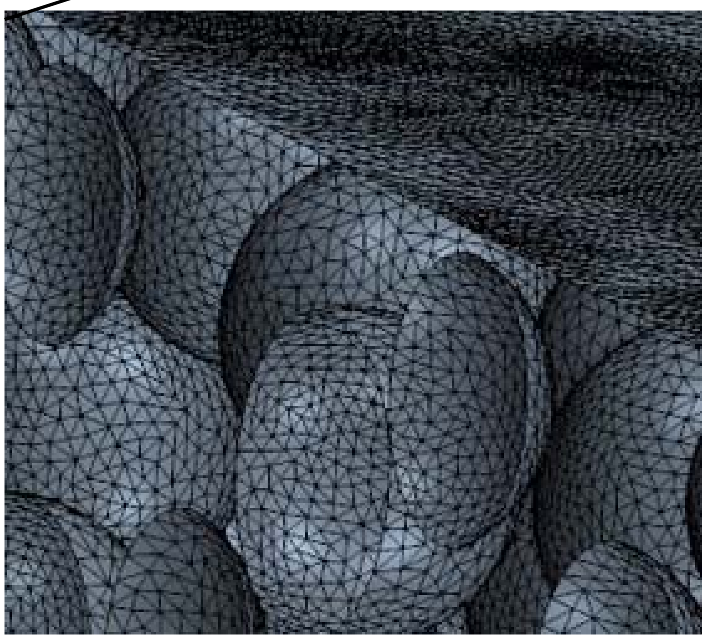


Response surfaces for different formulations
Each surface gives the optimum for ~500 variations. This would take decades and $$$$ by formulate-and-test

How do we carry out this kind of modeling?

Meshing
- Finite element
- Finite volume
- Finite difference





Highly parallel computer, 240 CPUs, 1.5 TB RAM
Starting from known boundary:
- Using electrochem equations calculate change in potential, current density etc. from cell to cell
- Repeat recursively until convergence, you run out of computer time or patience – can take several hours

Can take ½ billion or so mesh elements
DO NOT TRY THIS AT HOME!

ZnNi plating

"ZnNi is not Cd!" (Nihad Ben Salah, Heroux Devtek)

Life may go better with Coke
But it was easier with Cd (or Zn, or Ni)

- We are replacing Cd in aerospace and Zn in automotive with ZnNi
  - It is easy to plate an element
    - Get the plating parameters right and Faraday's law takes care of the rest
  - Once you have 2 elements they don't necessarily deposit in the same ratio as in the electrolyte
    - And that ratio can vary with plating voltage, current density, electrolyte flow rate….
    - So that means the coating chemistry, microstructure and performance can vary across complex components
    - You can even go from galvanically protective to galvanically corrosive in different areas
    - Zn → Ni

"A compound is 2 or more elephants comically combined."
My high school chemistry teacher

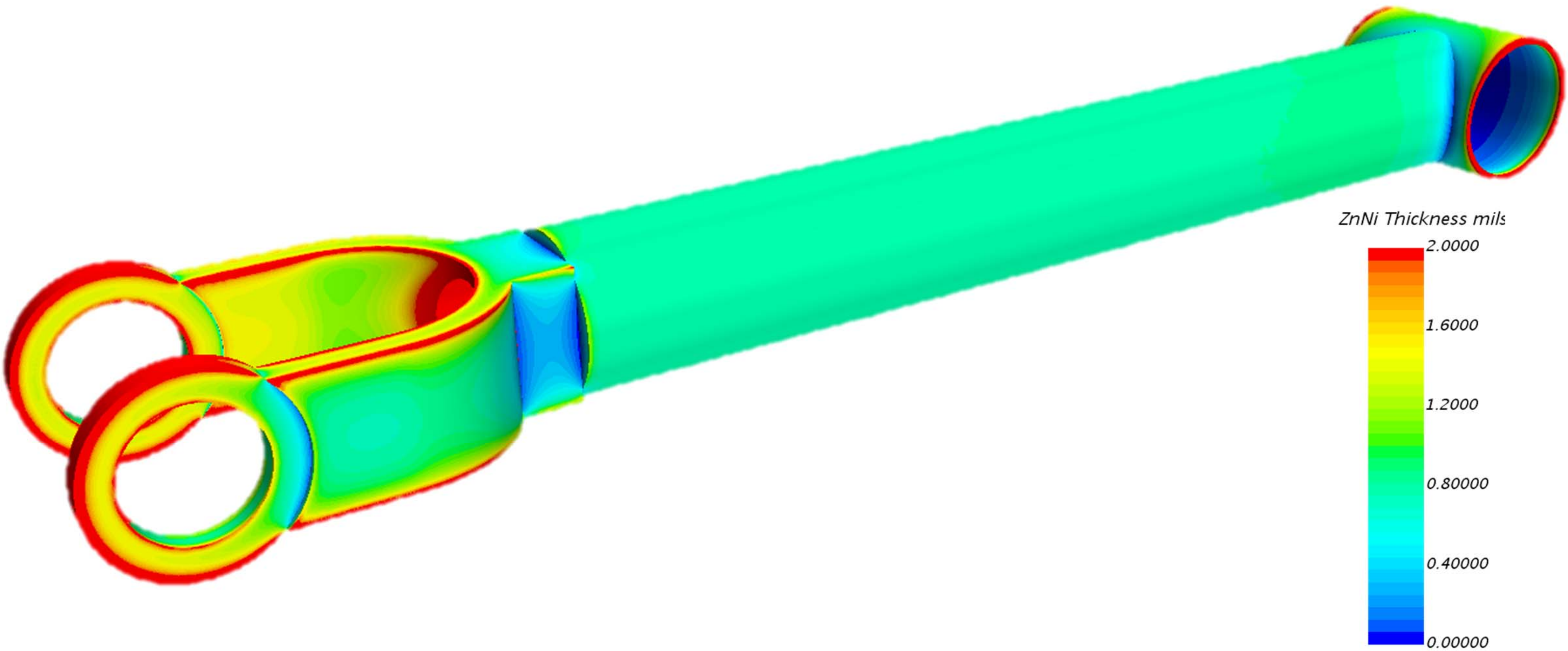
One elephant is hard enough to handle

Two is **more than** twice as hard

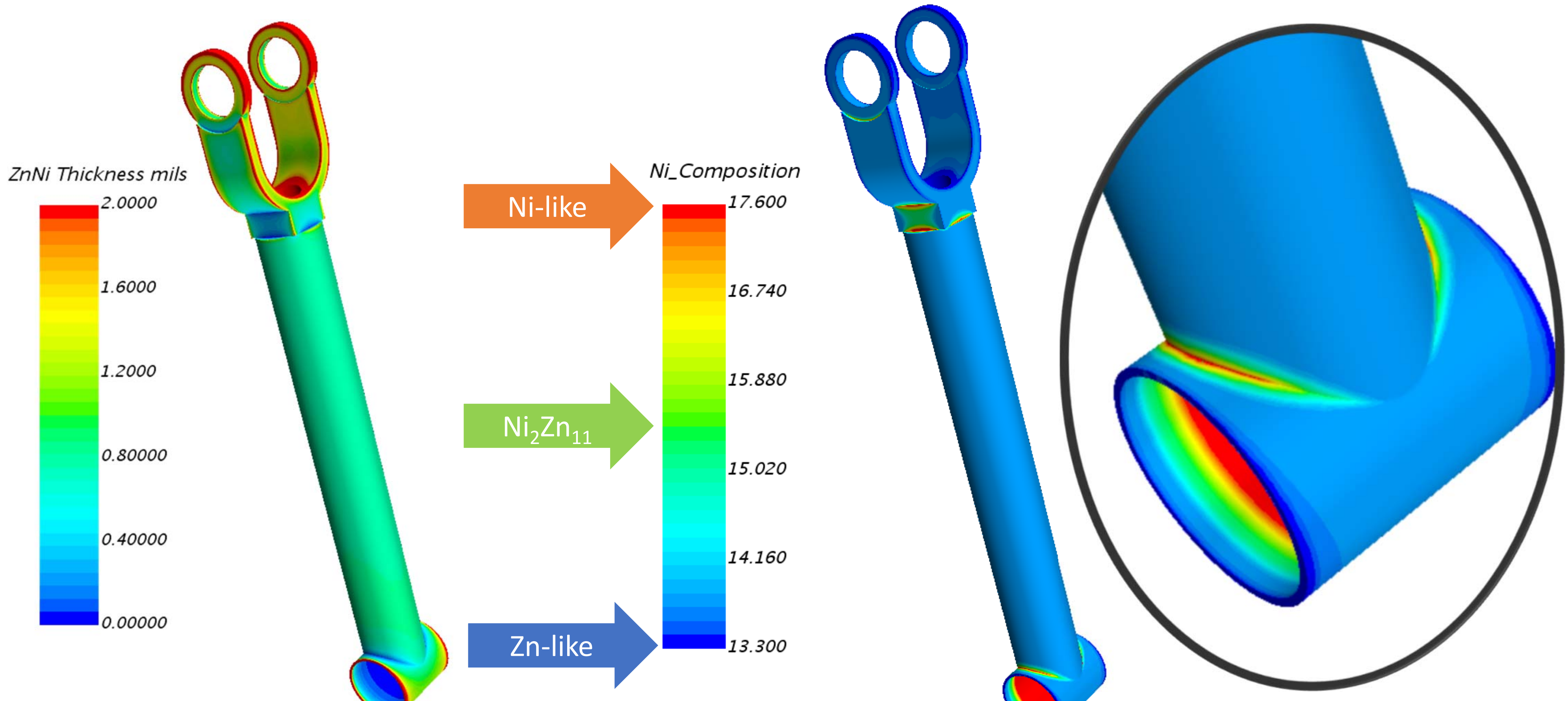
Tooling design for ZnNi

- If you want to plate ZnNi for aerospace, your tooling must be designed by electrodynamic simulation and sometimes computational fluid dynamics to get the right chemical and thickness uniformity
- Zn/Ni ratio varies with current density and current density varies over complex shapes, holes, etc.
- Have to model component, anodes, secondary anodes, robbers
  - Electrolyte is opaque so you can’t wand it
- Complex parts may also require modeling fluid flow, eductors, etc.

Thickness variation

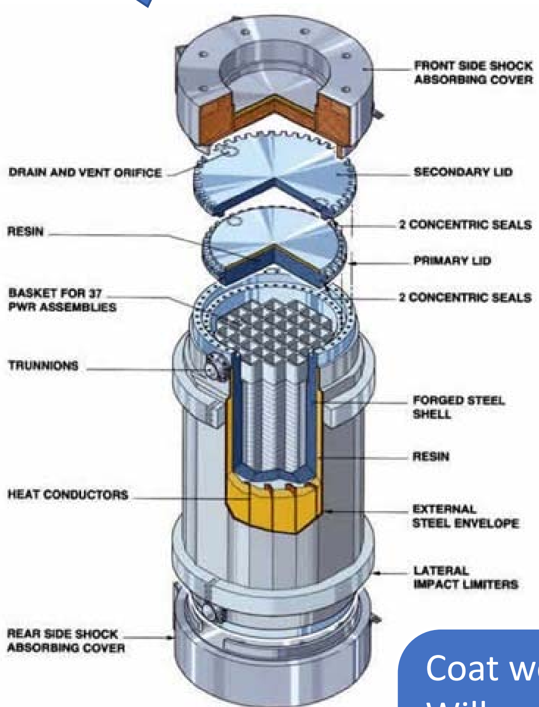


ZnNi thickness & composition with auxiliary anode



Very important: Low current density gives low thickness with high Ni%

E.g. Dry Storage Canisters - store nuclear fuel rods for 50 yrs



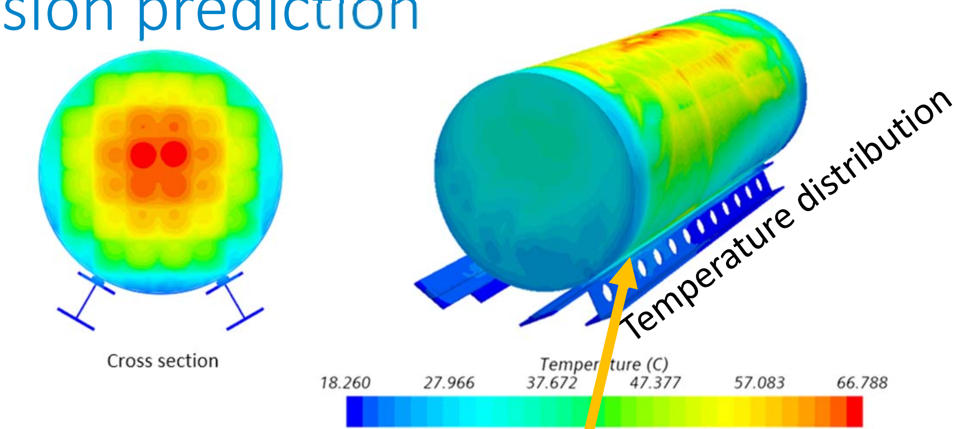
Coat welds to prevent corrosion
Will welds fail by stress corrosion cracking?
Which is faster?

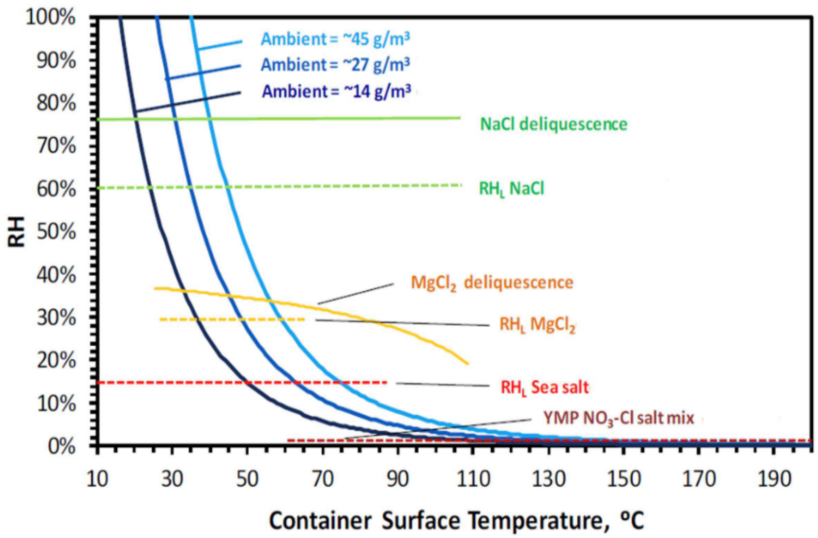
- 50 years of testing?
- Or a 50-year corrosion model?

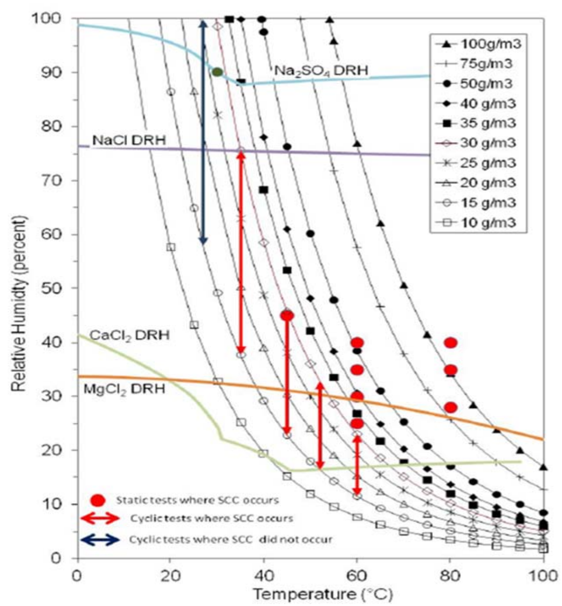
Nuclear Dry Storage Canister corrosion prediction

Worst case:

- Canisters in coastal locations
- Everything is fine until they cool down
- Different salts deliquesce at different temperatures during diurnal and seasonal temperature oscillations
- Corrosion occurs first at rail – worst place for crevice corrosion







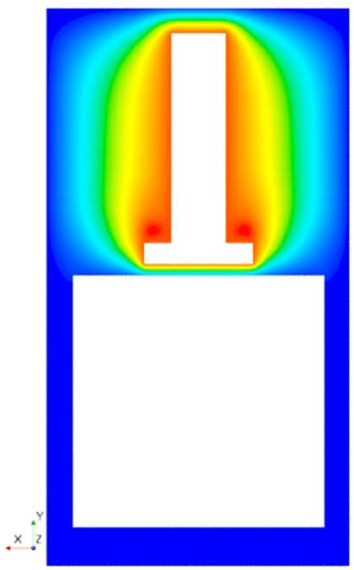
It starts corroding, not when it is hot, but as it cools. And the corrosion will start at the worst possible place – where the rails meet the DSC

Machining turbine engine components, gun rifling and other complex parts

- Today's solution: Electrochemical Machining (ECM)
  - ECM is corrosion gone mad – the ECM tool rapidly corrodes holes in very hard alloys
  - But hole dimensions are a complex function of tool shape, voltage, etc.
  - The only way to design a tool is multiple iterations of trial and error – very costly and uncertain
    - Takes many months and even then you may not get good enough tolerance
- Possible new solution: Develop an ECM model to calculate the required tool shape
  - But how can you model a process with so many variables?
    - Electrochemical properties of the tool and workpiece alloys
    - Electrochemical properties of the electrolyte – what electrolyte is best?
    - DC or pulsed current
    - Machining rate
    - Removal of heat, debris, bubbles, etc.
  - Ideally: Mathematically unmachine the part to determine the tool from the finished product
    - It turns out we cannot do that, but we can model hundreds of tool shape iterations to optimize the tool
    - Once the ECM model exists we can quickly and reliably design tools to machine any shape

Another real-life example: Electrochemical machining of turbine engine components, gun rifling and other complex parts made of hard-to-machine materials

- The problem:
  - Gas turbine engines require many very complex parts fabricated from Ni-based super alloys that are extremely complex and difficult to machine.
  - Rifling grooves in canons and last channels in other weapons are very hard to machine

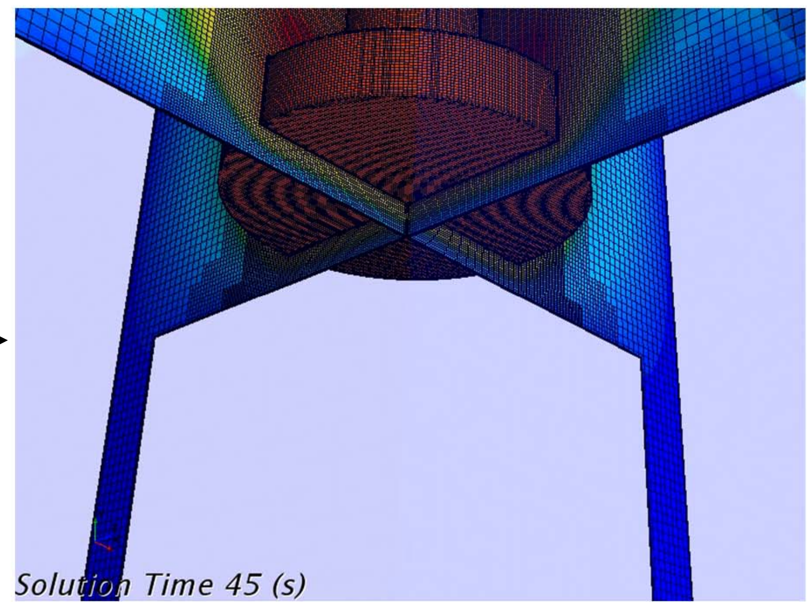


Solution Time 45 (s)

Die sinking

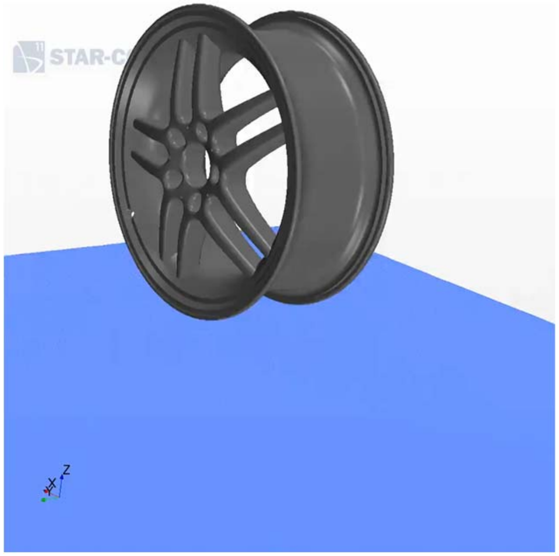
Current density

Mesh



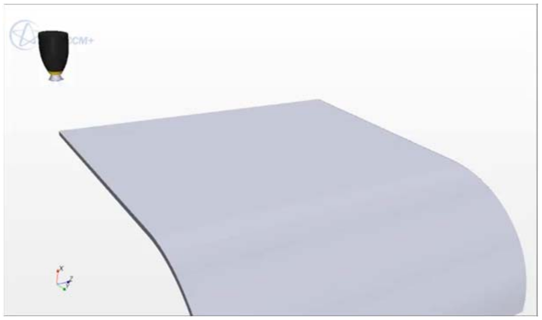
Some other applications

Plating coverage and uniformity for barrel plating, dip spin coating, etc.



Improved processing for cleaning, painting, other dip processes

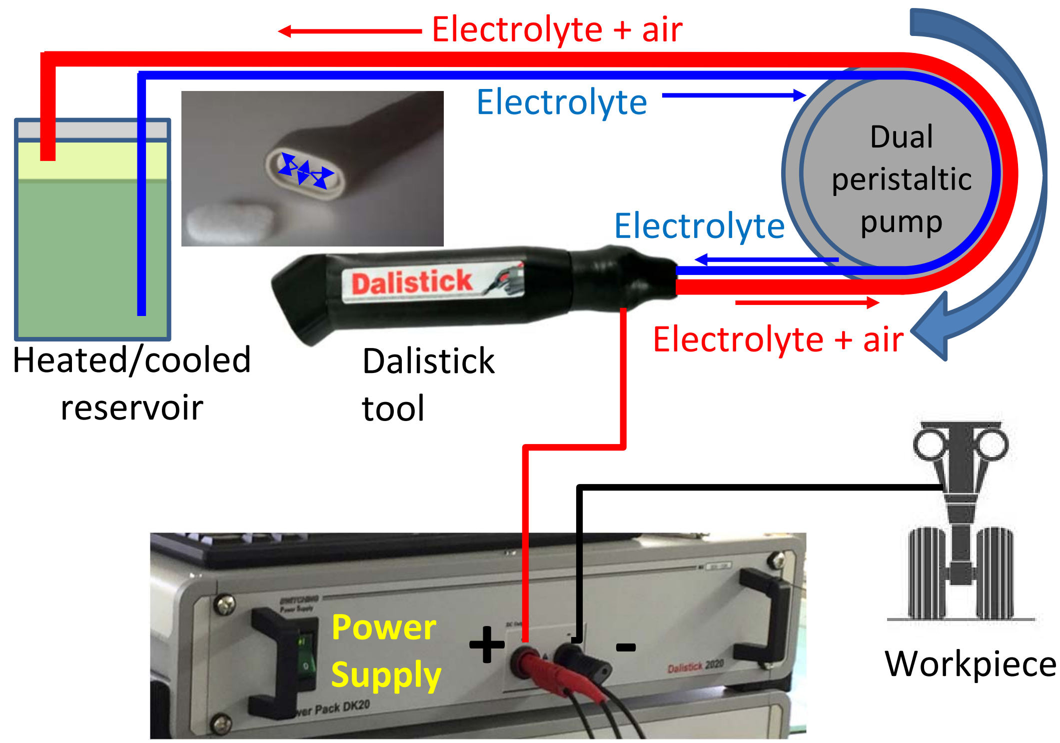
Optimizing paint usage and coverage, tool path planning for painting, thermal spray, cold spray



Non-drip brush plating

For the tool to be non-drip the fluid moving out of the pad must be balanced by the air flowing in.

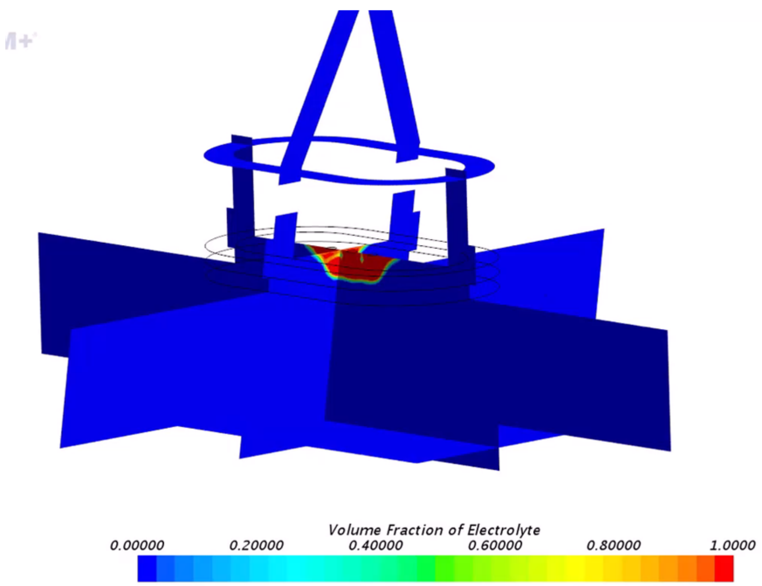
Whenever we design a new non-drip brush plating system we use a combination of computational fluid dynamics and electrodynamics to ensure the tool will not drip and will plate uniformly



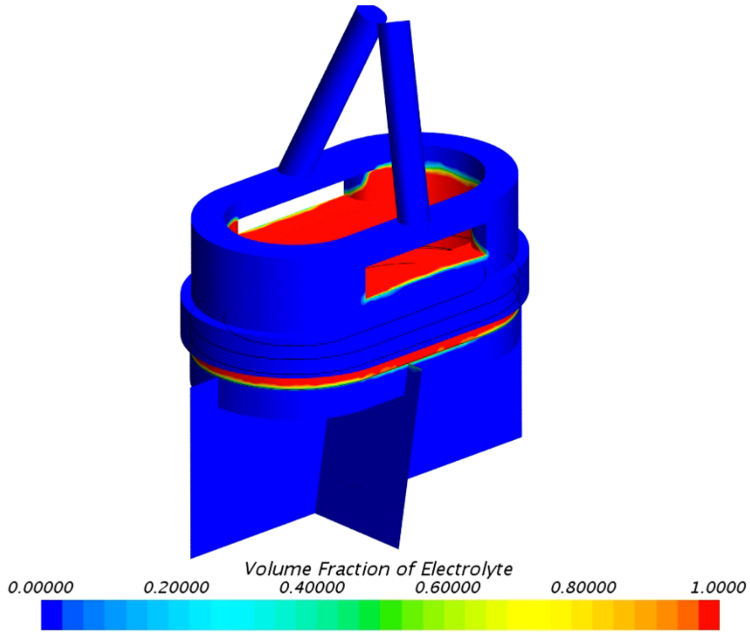
- Closed-loop electrolyte system from Dalic, France
- Electrolyte is pumped through plating tool and air + electrolyte sucked back to tank
- Balanced electrolyte/air flows keep pad wet but non-drip

Using CFD and computational electro-chemistry to scale up non-drip tools

CFD model predicts dripping



CFD model predicts non-dripping



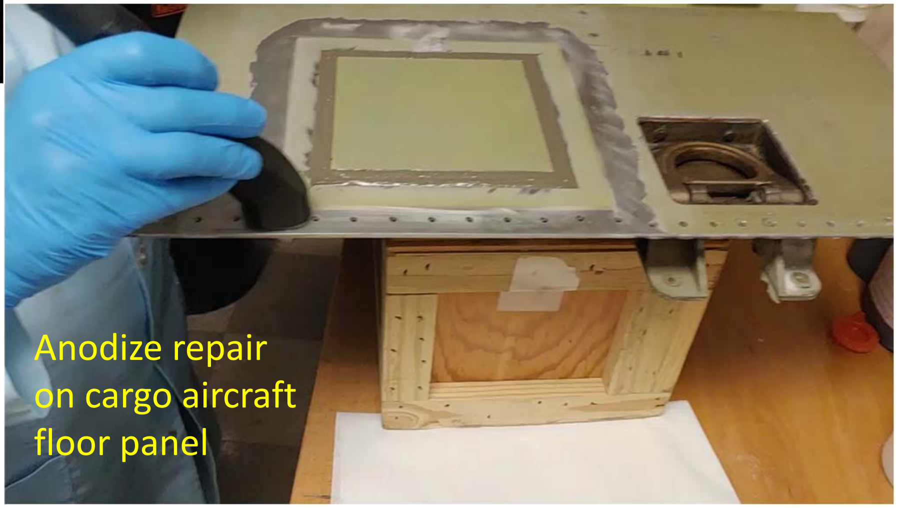
On-aircraft non-drip brush anodizing


Anodizing P-8 Static Port

Original tool designed by trial and error:

- Does not drip when used overhead/upside down
  - But electrolyte coalesces and runs down, requiring catch basin.
- Does not drip through holes or over edges
  - But does leave water droplets on surface

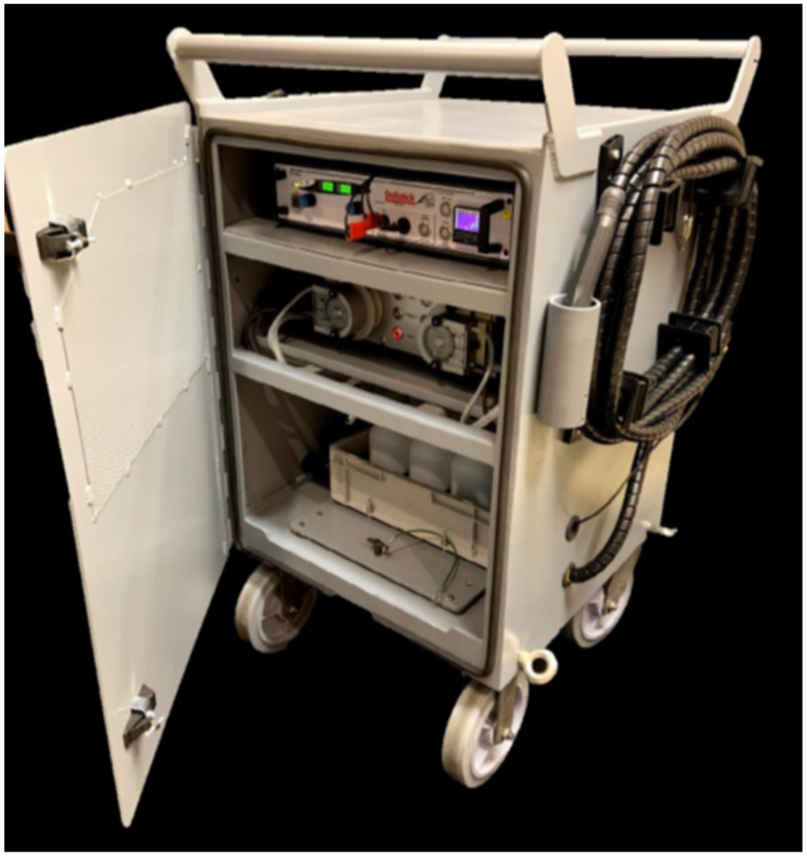
If you could easily design larger or different shaped tools it would open up a whole new approach to on-aircraft coating repair.
Problem:
Design a tool to repair much larger areas


Anodize repair on cargo aircraft floor panel

Commercial non-drip plating system

- F-35 Ground Support Equipment
- Ruggedized to operate wherever there are F-35 squadrons
  - Including topside on aircraft carriers
- Currently supplying 50 units, for repair of ZnNi plating on the growing number of F-35 squadrons around the world
- **Absolutely no FOD**

Existing non-drip tool is ideal for this type of small-area touch-up repair



Commercial non-drip Ground Support Equipment for F-35 ZnNi repair

CFD + Electrodynamic modeling makes it possible to anodize much larger areas

- **No – we are not anodizing whole floor**
- Cargo floor anodize repair around patches
- Aim: Repair each patch area in 20 minutes or less
  - Requires a tool 6x area
  - You could spend months designing by trial and error
  - Or a few days designing by computational methods
- Of course a much larger tool requires redesigning the whole system
  - Pumping, cooling, power supply, etc.
- This project now underway

A more complex brush plating and anodizing repair

Problem:

Design a non-drip repair system that will repair Al anodizing and fastener corrosion on an aircraft wing simultaneously

- Strip off the corrosion from the fasteners
- Repair the anodize around them
- Replate the fastener heads
- Equipment must deliver electrolyte and apply potentials uniformly over a long, narrow tool
- Minimize electrical and cooling needs
- Carry out repair in an acceptable time

On-aircraft processing at this scale cannot be done without computational methods

Who says you can't work and have fun at same time? Our intrepid explorers practice aircraft-climbing

A Model is Only as Good as its Data

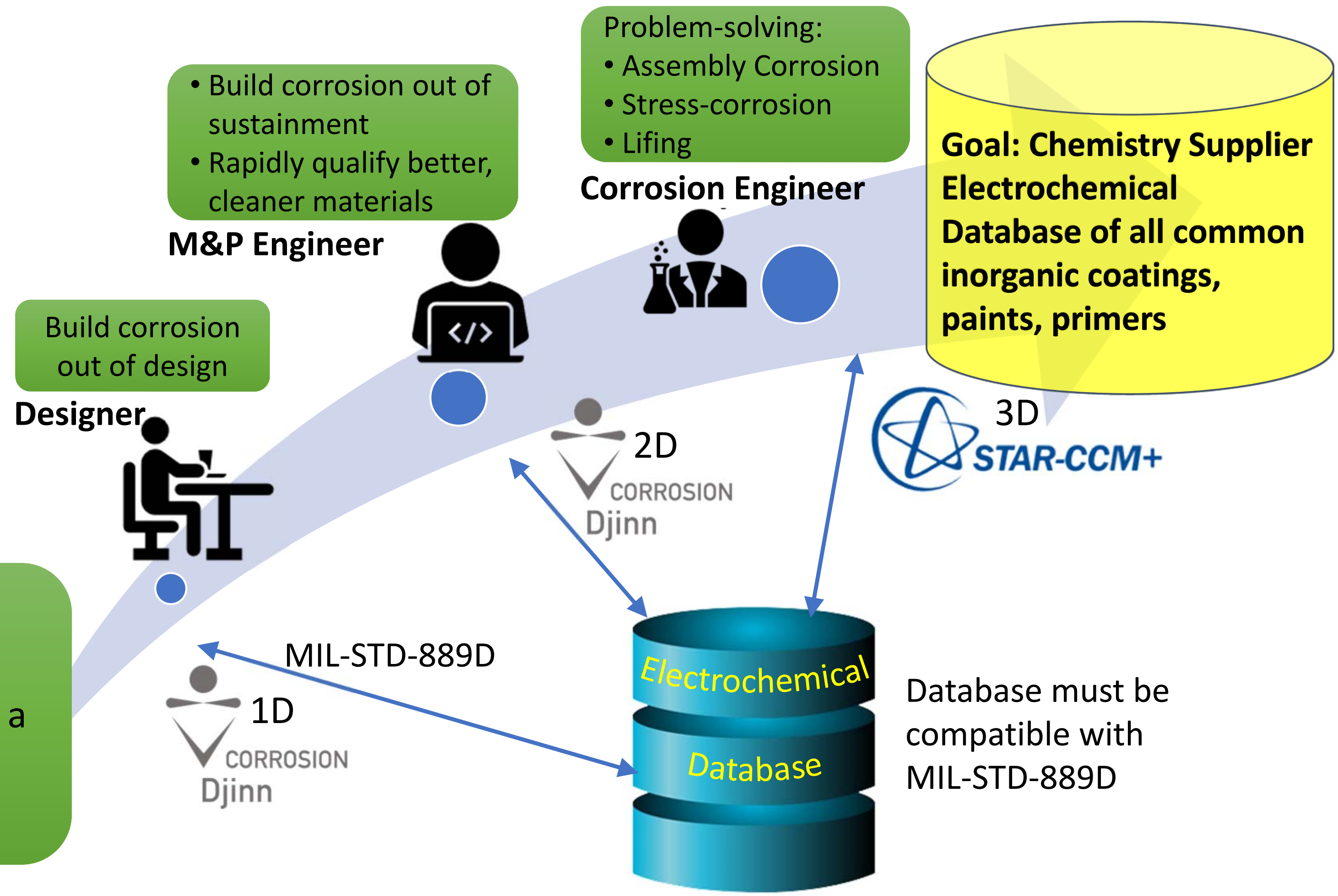
Accurate modeling requires accurate data

But it also requires that we agree on how to acquire and use data consistently

Comprehensive Corrosion Analysis Uses a Common Database of Polarization and other data

From design through sustainment:

- ✓ 1 integrated package
- ✓ 1 database
- ✓ 3 analysis tools
  - ❑ Design
  - ❑ Sustainment
  - ❑ Detailed analysis



As with all computational methods:
An electrochemical database is a big effort. But once you have it you can use it everywhere

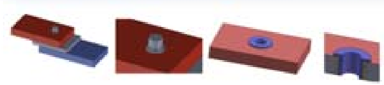
CORRDESA

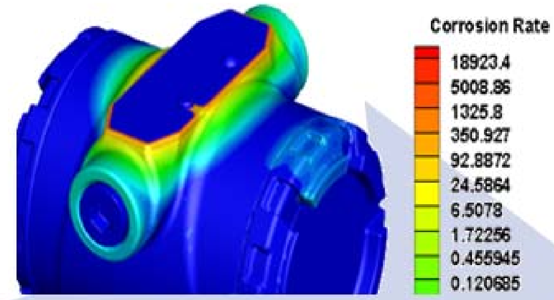
CORRDESA

TEAMCENTER

PLM Software

- Corrosion modeling software and Databases
- Predictive Basing Model for CBM and evaluating mitigation - predict corrosion of assets wherever they deploy





Several groups are now developing data and approaches for prediction of paint system degradation and location-based corrosion for Condition-Based Maintenance CBM+

CORROSION Djinn

MIL-STD-889D

1D Galvanic Corrosion

Corrosion rate of galvanic interfaces.

How serious is the problem? Mitigate by changing materials, finishes

Siemens Templated Geometry (2D/3D)

Simplified common geometries for corrosion location and severity. User chooses dimensions, materials, finishes

Where will it corrode? How badly? Mitigate by changing design, materials, finishes

Siemens Full FEA with Assistants/Templates (3D)

Full 3D analysis from CAD with Simulation Assistants, Templates for M&P Engineers

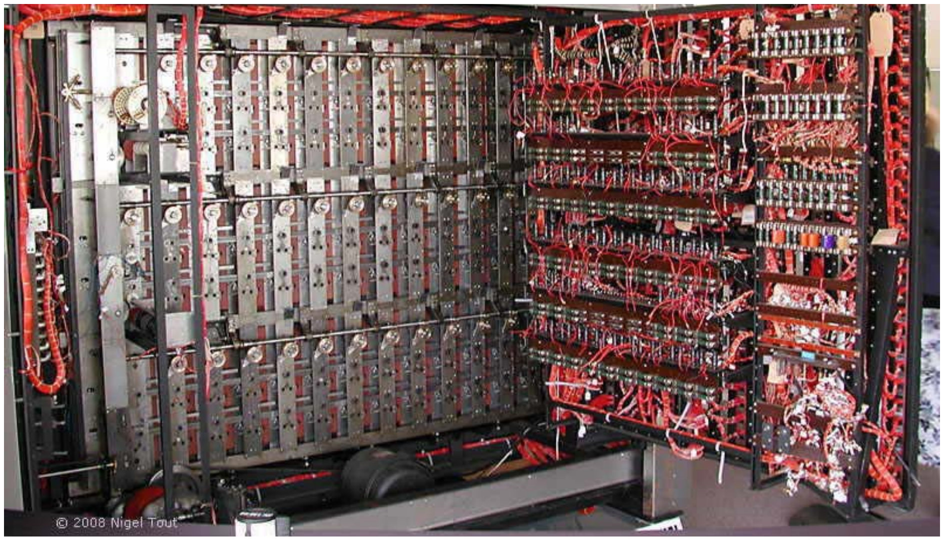
How will complex assemblies corrode in multiple environments? Mitigate by changing design, materials, sealants, paint systems

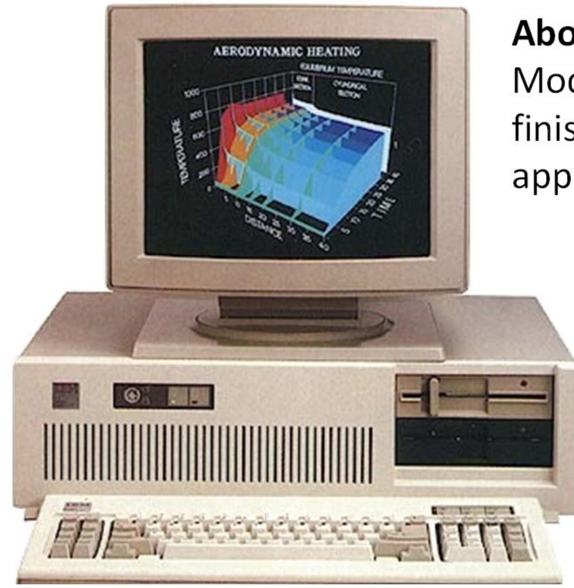
Others have alternative FEA approaches

STAR-CCM+

We've come a long way, baby

Alan Turing's Bombe that broke the Enigma code





About where we are today
Modeling for surface finishing is a recognized approach:

- Proving very useful for plating and some finishing processes
- Finding new uses as it develops
- But still a lot to learn

Veni, Vidi, Duci
I came, I saw, I calculated

Where we are going: Aiming to make modeling a standard, integrated approach to coating development and corrosion protection