Accelerated Electrochemical Machining Tool Design

COMSOL Conference 2017

Boston, MA

5 Oct 2017

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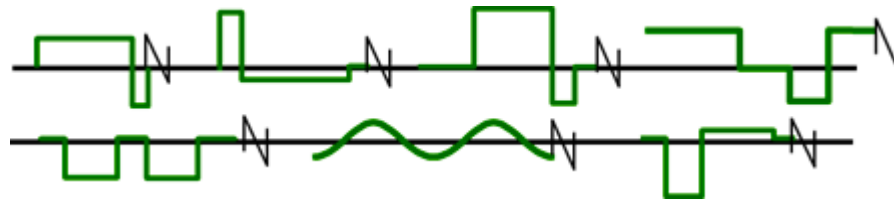
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Outline

- Electrochemical Machining (ECM)

- ECM Tests
  - Apparatus and Methods
  - Results and Characterization

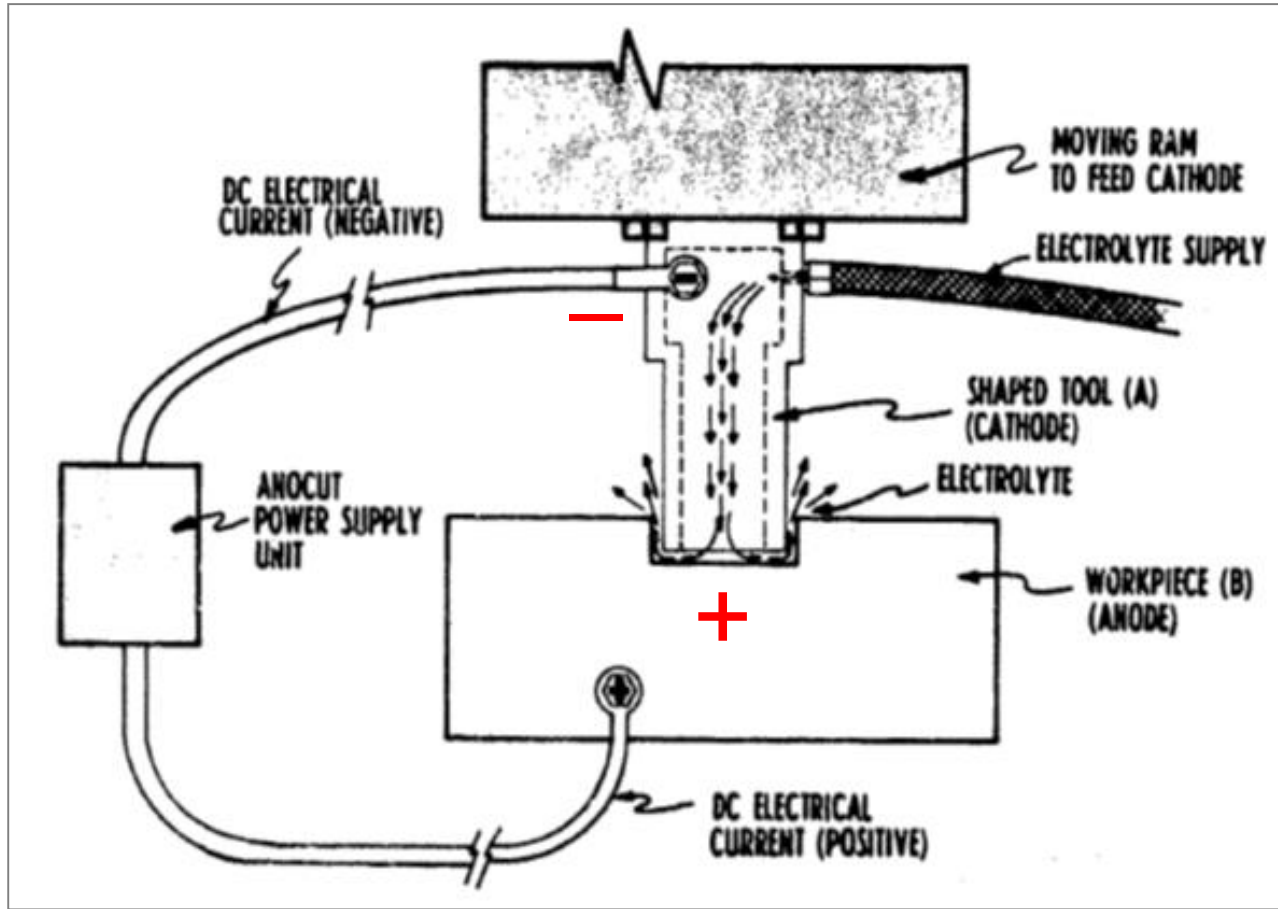- COMSOL® Modeling
  - Results and Comparison to Experiment

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Electrochemical Machining
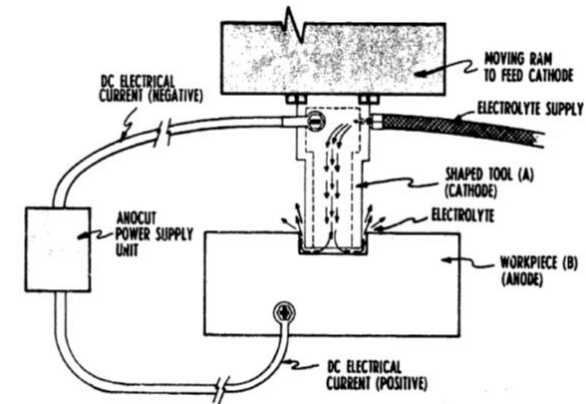
Electrochemical Machining

Electrochemical Machining

Key advantages[†]:

o   Applicability to difficult to cut materials,

  •   No tool wear/No (thermal/mechanical surface damage,

o   High material removal rate,

o   Smooth bright surface finish, and

o   Production of parts with complex geometry.

Key challenges[†]:

1.   Disposal of machining products ⬅ (prior Faraday)
2.   Electrolyte processing ⬅ (prior Faraday)
3.   Tool design ⬅ (current Faraday)
4.   Machining accuracy ⬅ (current Faraday)
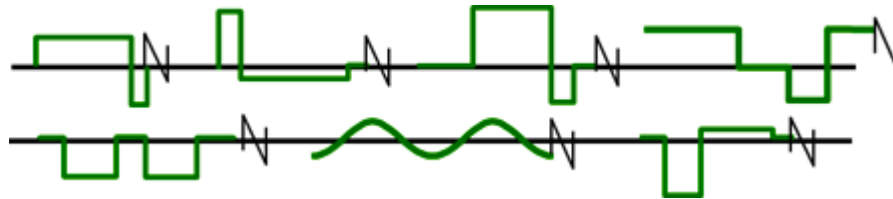5.   Process monitoring ⬅ (prior sensor/automation advancements)

Oil Grooves

Planetary Carrier

[†]K.P. Rajurkar, D. Zhu, J.A. McGeough, J. Kozak, A. De Silva, "New Developments in Electro-Chemical Machining" *Annals of the CIRP* Vol 82(2) 1999.
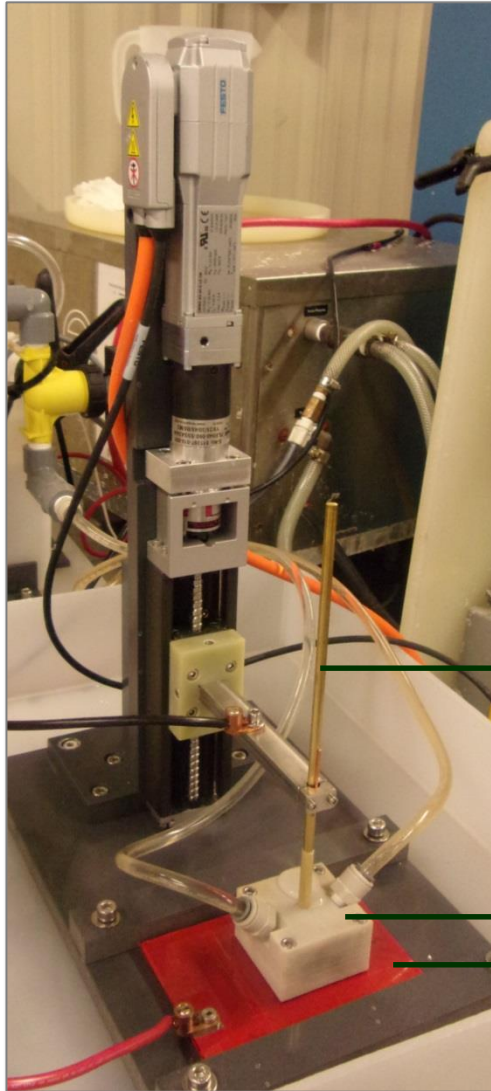
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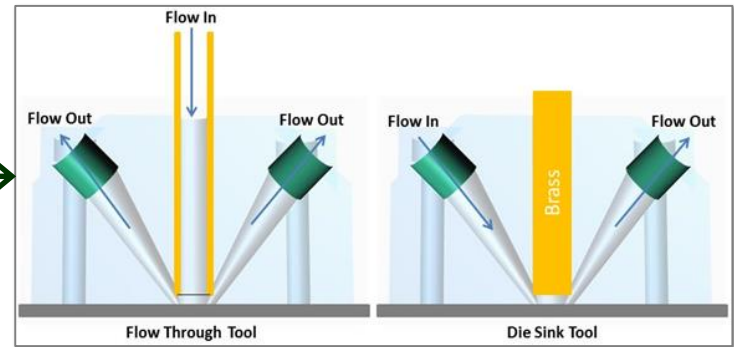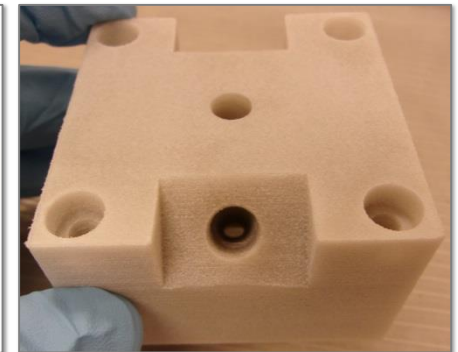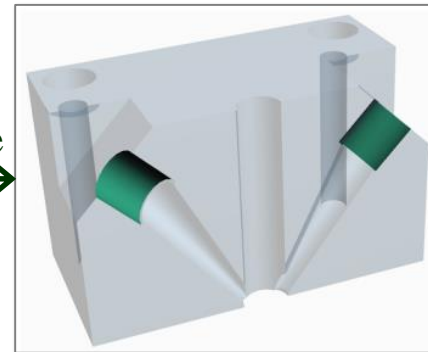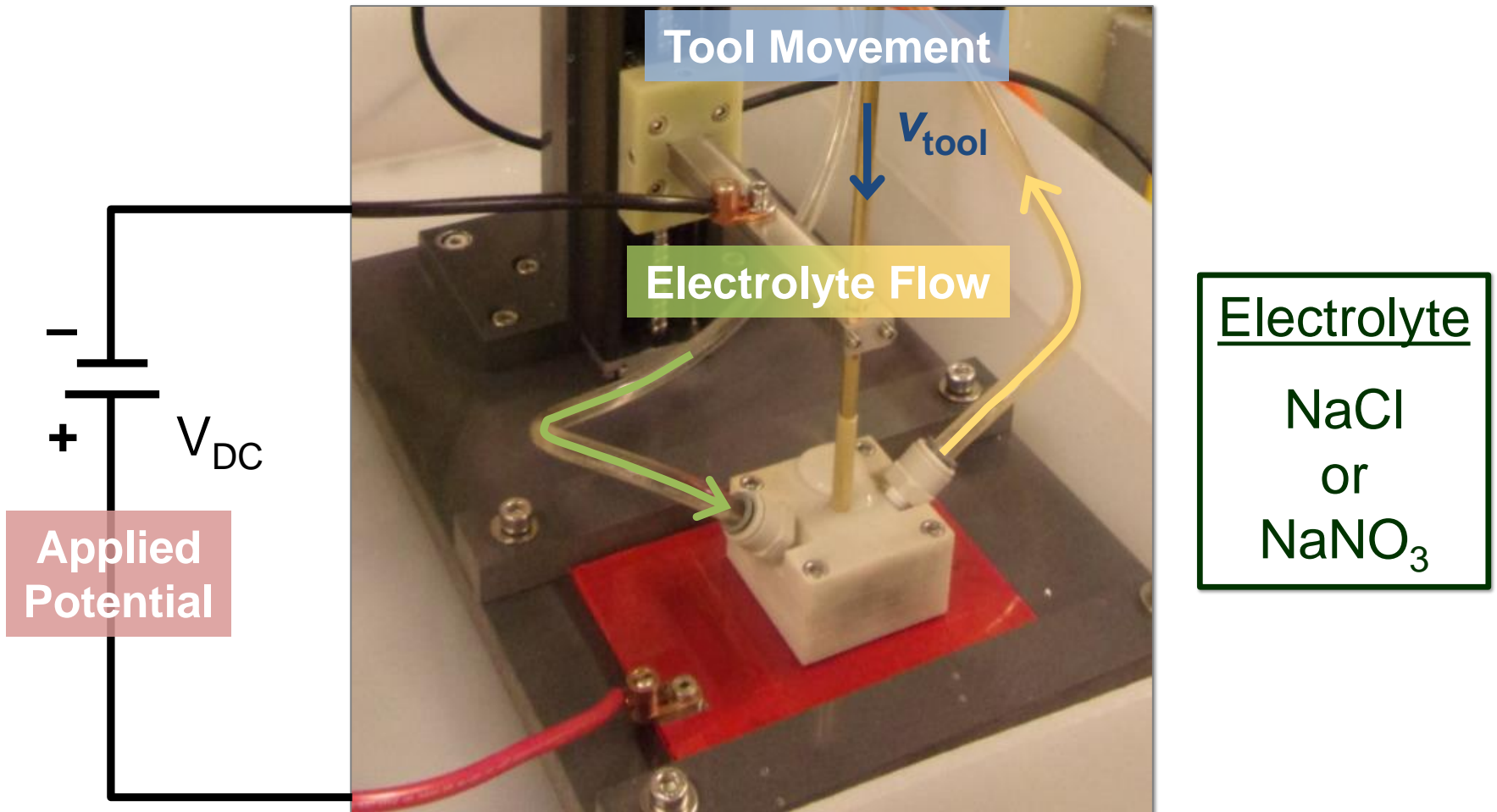# ECM Tests

ECM Apparatus

Rod or Tube Tool

3-D Printed
Flow Module

4130 Steel
Flat Panel
ECM Part

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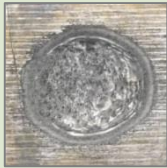
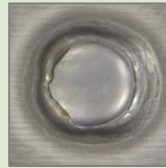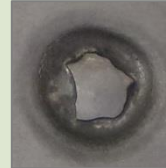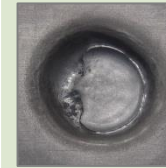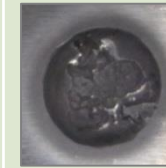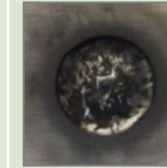# ECM Experimental Parameters

Tool Movement

V_{tool}

Electrolyte Flow

V_{DC}

– +

Applied Potential

Electrolyte

NaCl
or
NaNO$_3$

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ECM Tests – Results

Parameter	Units	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Tool	–	Rod	Rod	Rod	Tube	Rod	Rod	Tube
Electrolyte	–	NaCl	NaCl	NaCl	NaCl	NaCl	$NaNO_3$	$NaNO_3$
V_{DC}	V	5	5	15	10	10	10	10
v_{tool}	in/min	–	0.012	0.006	0.006	0.006	0.006	0.006
δ_o	in	0.050	0.050	0.075	0.075	0.075	0.075	0.075
Δt	min	20	4.3	20	20	20	16	14
Photo								

Preliminary Tests

Test Matrix

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ECM Test Matrix – Characterization

Rod Tool

Tube Tool

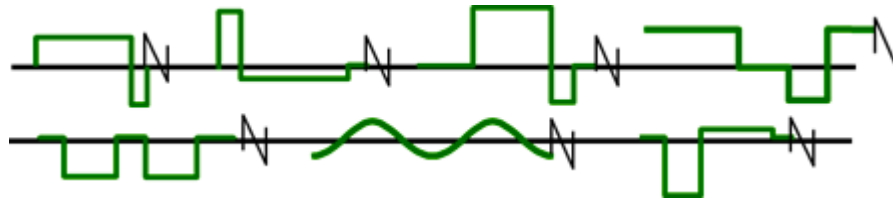**NaCl** **NaNO$_3$** **NaCl** **NaNO$_3$**
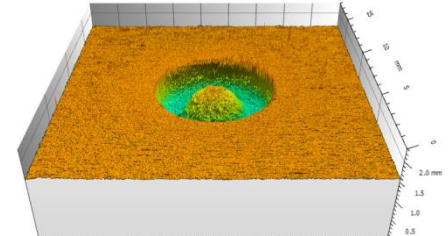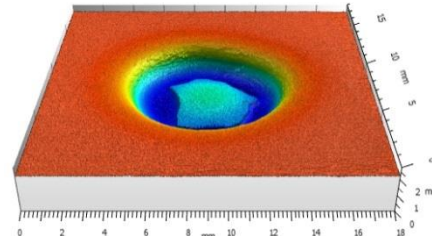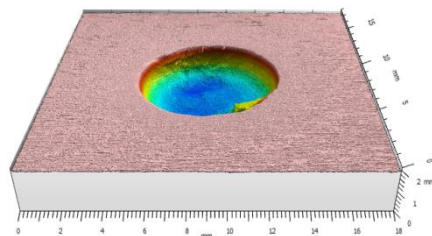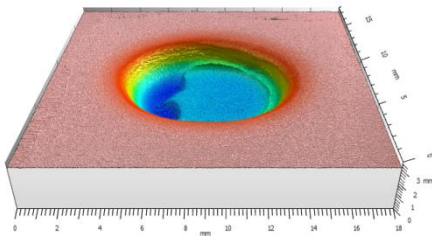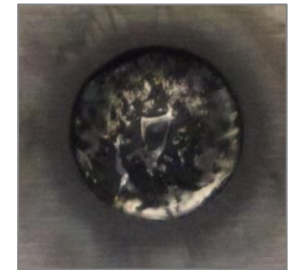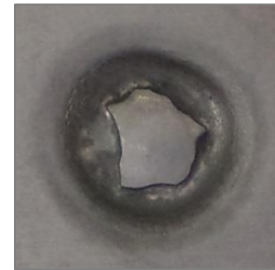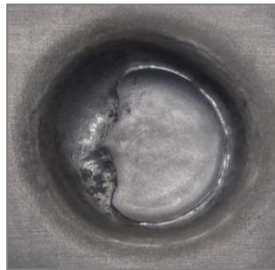
- **Rod Tool → Flat Base**
- **Tube Tool → Mounded Base**
- **NaCl → Wider, Faster ECM**
- **NaNO$_3$ → Tighter, Slower ECM**

- **Suboptimal Fluid Flow → Irregular Edges**

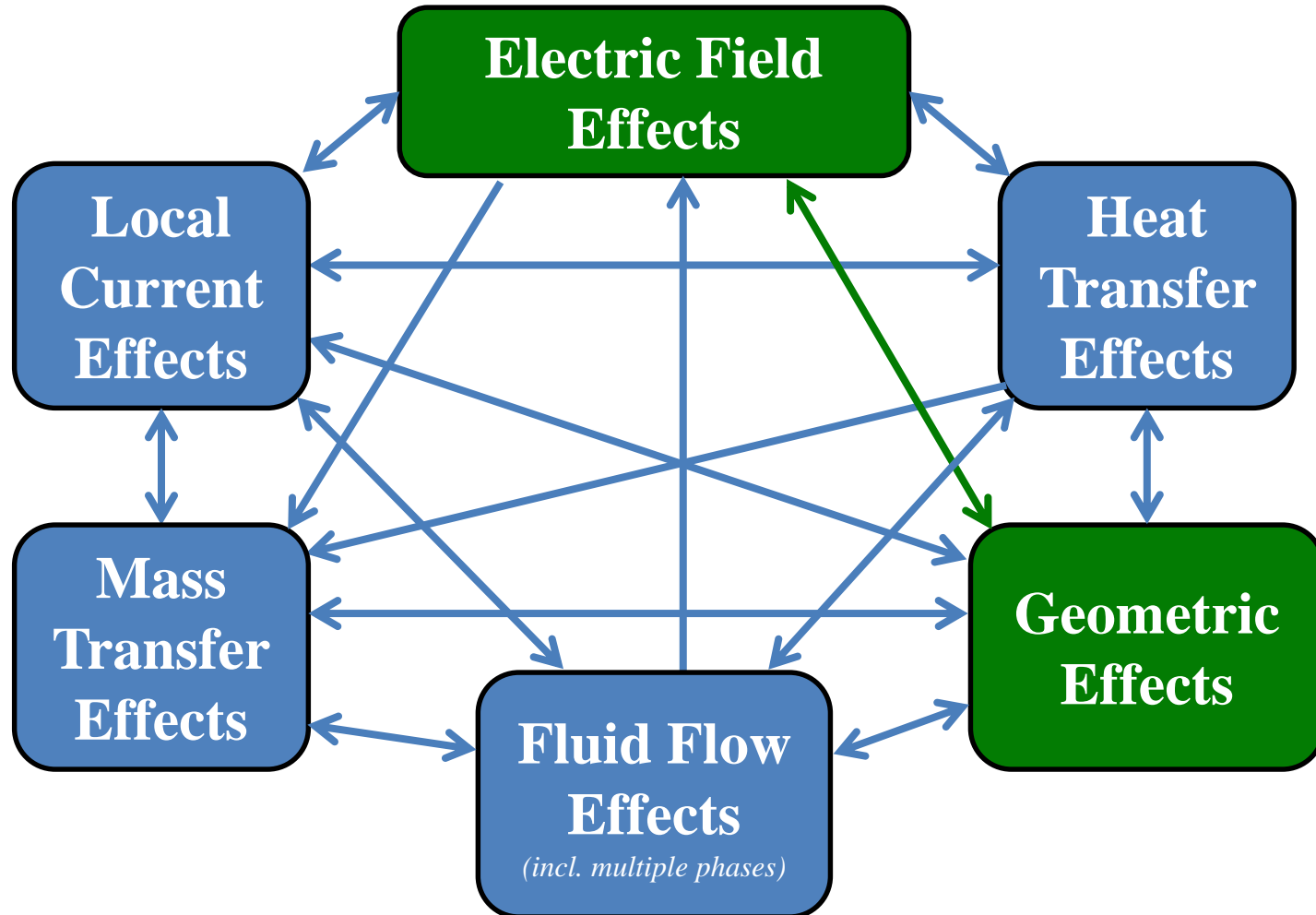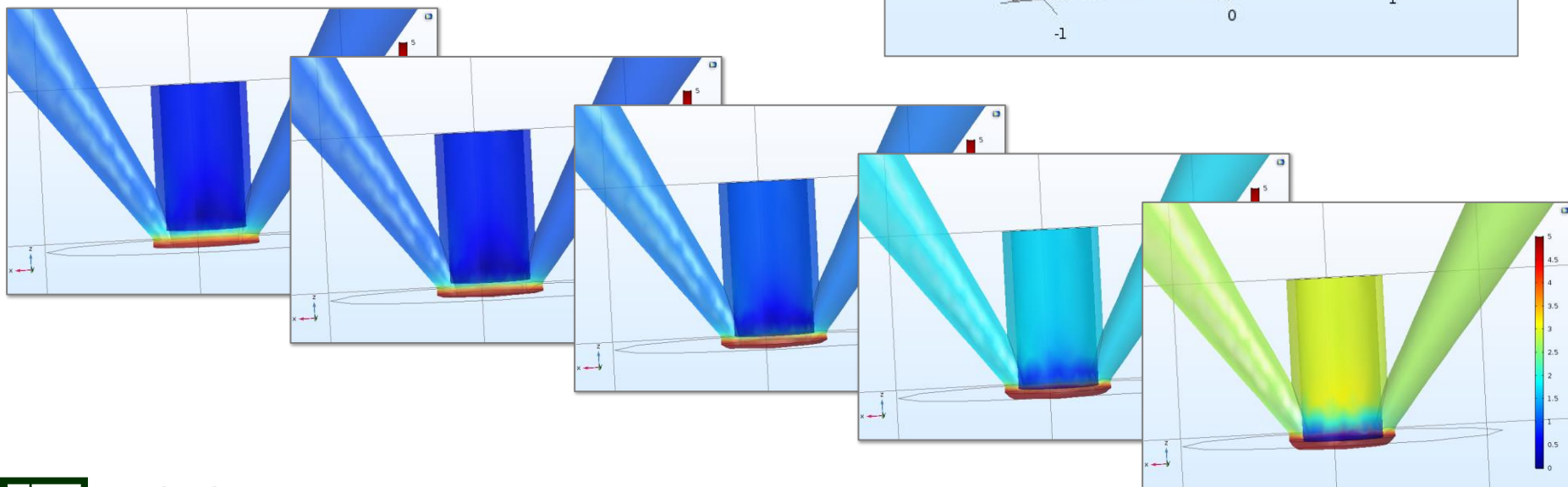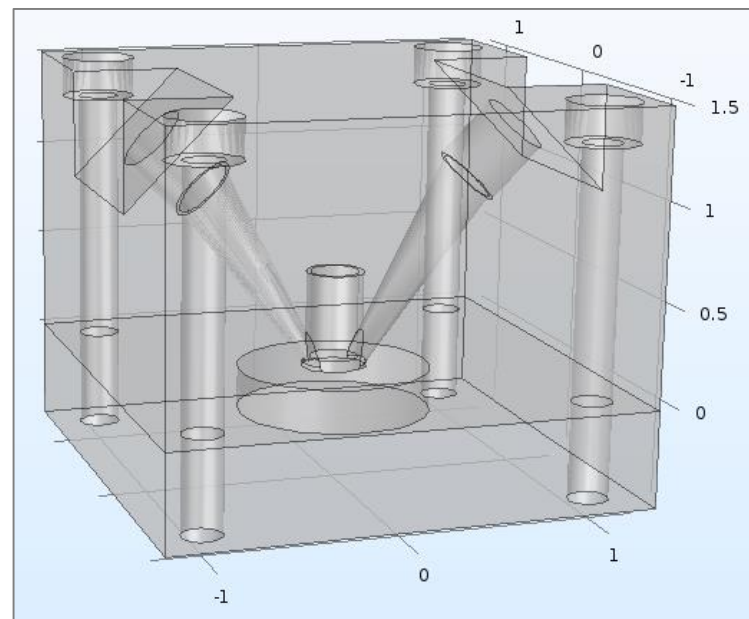**FARADAY TECHNOLOGY, INC.**

COMSOL® Modeling

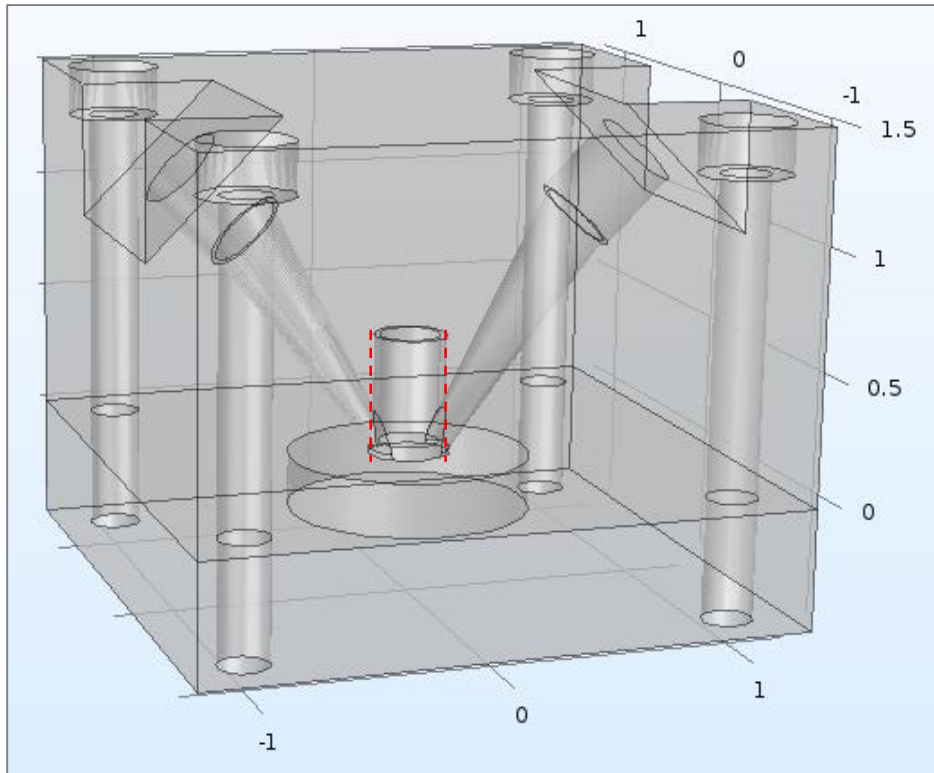# Modeling – Evaluation of Physical Phenomena

Modeling – COMSOL Functionality

COMSOL Electrodeposition Module

o 3-D Model Import

o No Flow

o Primary Current Distribution Only
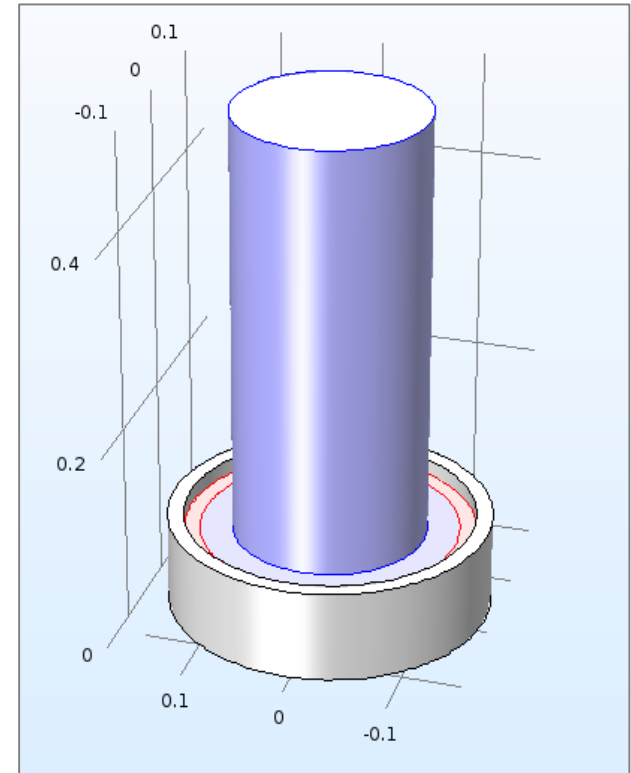
o Multiphysics – Deforming Geometry

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Modeling – Rod/Tube Tool Tests

**Rod Tool
Cross-Flow**

**Tube Tool
Flow-Through**

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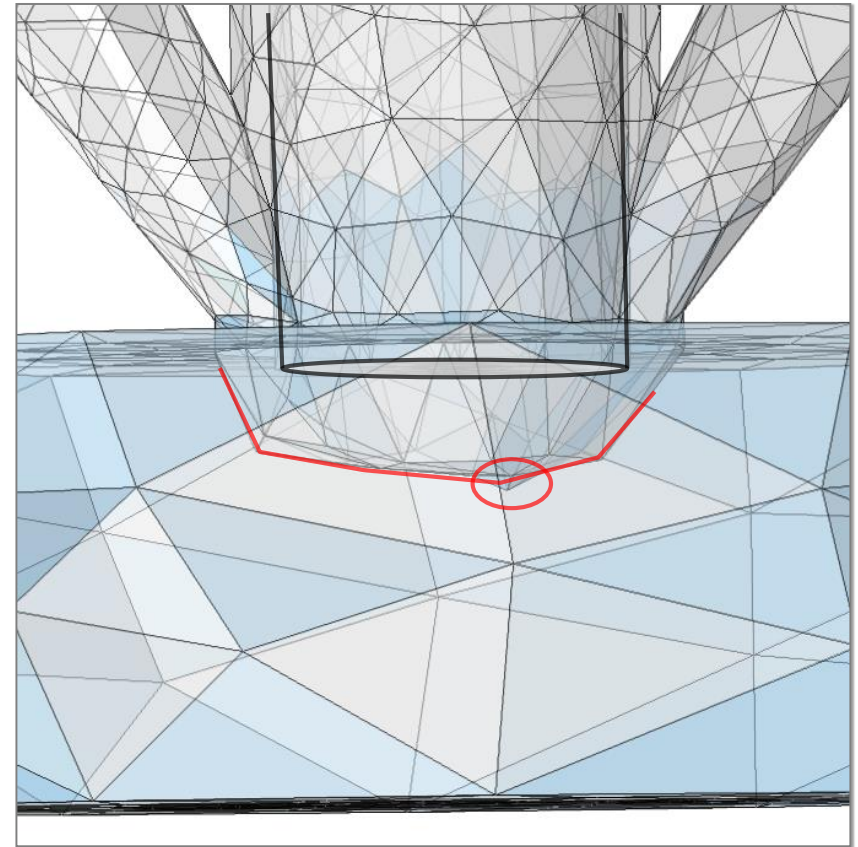
Modeling – Mesh Construction/Evolution Challenges
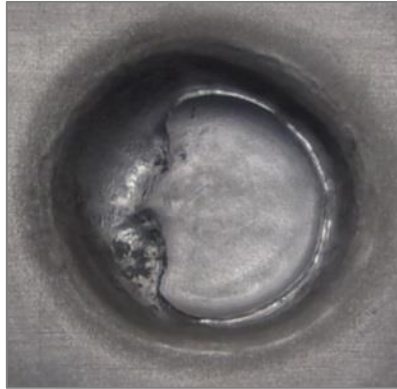
- Insufficient mesh density on deforming surfaces

- Spurious deformed mesh geometries

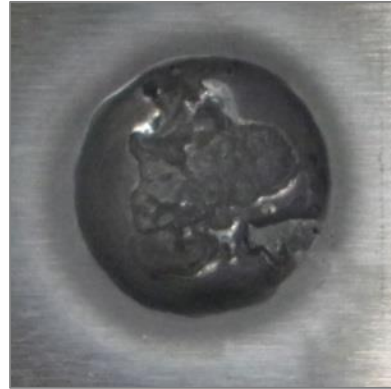- Recalcitrant 'Inverted mesh element' errors

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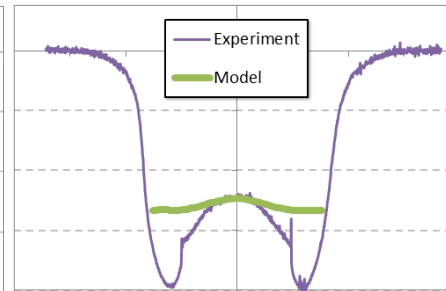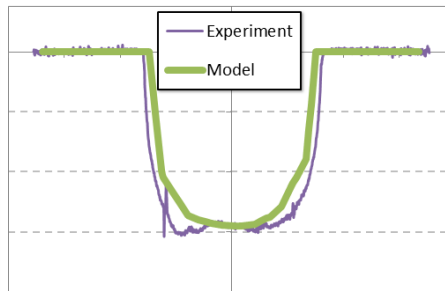**TECHNOLOGY, INC.**

Modeling – ECM Test Matrix

Rod Tool

NaCl	NaNO$_3$

Tube Tool

NaCl	NaNO$_3$
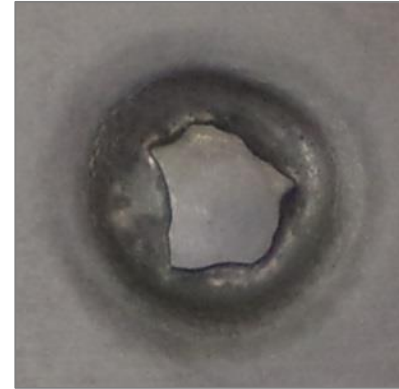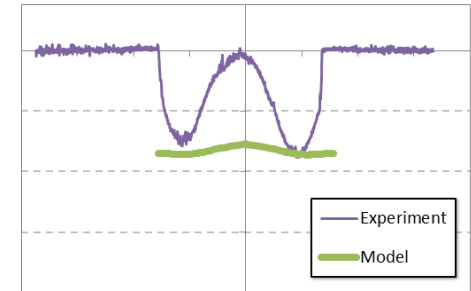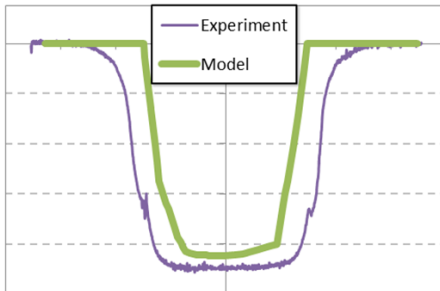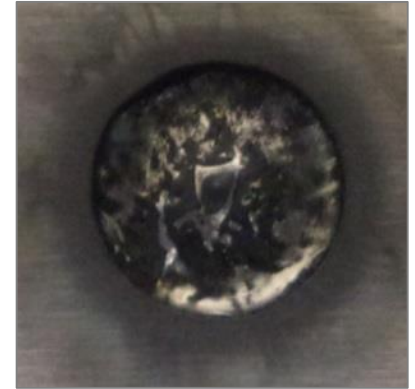
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Summary

o GOAL: Multiphysics modeling for rapid, accurate ECM tool design
  Reduce/eliminate multiple prototyping steps

o Fabricated basic bench-scale ECM apparatus

o Demonstrated ECM of 4130 steel with cross-flow (rod) and through-flow (tube) flow configurations

o Preliminary COMSOL modeling
(no flow, 1° current distribution only)
yields good match to subset of experimental ECM profiles

   o *Subsequent modeling to include flow, surface effects*

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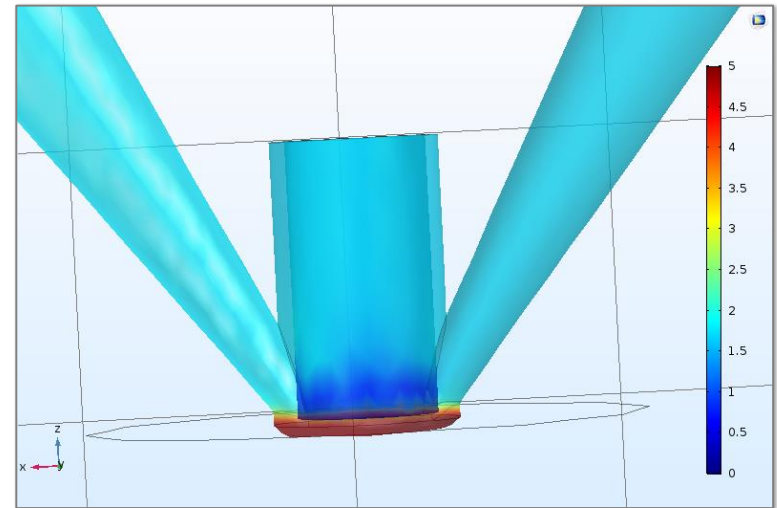
Acknowledgment

- This material is based upon work/resources supported by:
  - Commercial Partners
  - SBIR/STTR Grants
  - Faraday Corporate

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Thank You!