



ARL-TM-2015 • DEC 2015



# **Volume I: Select Presentations**

**by ARL Summer Student Research Symposium**

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14. ABSTRACT <p>The ARL Summer Student Research Symposium is an ARL Director's Award Program for all the students participating in various summer scholarship and contract activities across ARL. The goal of the program is to recognize and publicize exceptional achievements made by the students and their mentors in the support of Army science.</p> <p>All college undergraduate and graduate students receiving research appointments and conducting summer studies at ARL are automatically enrolled in the symposium program. As an integral part of their summer study, all students are required to write a paper on their work which summarizes their major activity and its end product.</p> <p>The program is conducted on two separate competitive levels: undergraduate and graduate. The format of the paper in both levels is the same. However, the evaluation will take into consideration the difference in the academic level of the students.</p> <p>All students submitted their research paper for directorate review. Directorate judging panels selected one or two papers from each competition category for the laboratory-wide competition at the Summer Student Symposium on 7 August 2015.</p> <p>Students selected by their directorate for competition participated in the one-day Summer Student Symposium on 7 August 2015. At the symposium the students gave presentations on the focuses of their research papers to the ARL Director and an ARL Fellows panel.</p> <p>This volume of the Summer Student Symposium Proceedings contains many of the presentations that the selected students gave at the symposium.</p>					
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## Director's Foreword

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The U.S. Army Research Laboratory (ARL) mission is to “Provide innovative science, technology, and analyses to enable full spectrum operations.” As the Army’s corporate laboratory, we provide the technological underpinnings critical to providing capabilities required by our current and future Soldiers.

Our nation is projected to experience a shortage of scientists and engineers. ARL recognizes the criticality of intellectual capital in generating capabilities for the Army. As the Army’s corporate laboratory, addressing the projected shortfall is a key responsibility for us. We have, therefore, identified the nation’s next generation of scientists and engineers as a key community of interest and have generated a robust educational outreach program to strengthen and support them. We have achieved many successes with this community. We believe that the breadth and depth of our outreach programs will have a significant positive effect on the participants, facilitating their journey toward becoming this Nation’s next generation of scientists and engineers.

A fundamental component of our outreach program is to provide students research experiences at ARL. During the summer of 2015, we supported research experiences at ARL for over 175 undergraduate and graduate students. Each of these students writes a paper describing the results of the work they performed while at ARL. All of the papers were of high quality, but only a few could be selected for presentation at our student symposium. Several of the presentations for the selected research papers prepared this summer are contained in this volume of the proceedings, and they indicate that there were many excellent research projects with outstanding results. It is unfortunate that there was not enough time for us to have all of the papers presented. We would have enjoyed hearing them all.

We are very pleased to have hosted this outstanding group of students for the summer. It is our hope that they will continue their pursuit of technical degrees and will someday assist us in providing critical technologies for our Soldiers.



Thomas P. Russell  
Director

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## Introduction

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The ARL Summer Student Research Symposium is an ARL Director's Award Program for all the students participating in various summer scholarship and contract activities across ARL. The goal of the program is to recognize and publicize exceptional achievements made by the students and their mentors in the support of Army science.

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Students selected by their directorate for competition participated in the one-day Summer Student Symposium on 7 August 2015. At the symposium, the students presented their papers to an audience of ARL scientists and engineers, including the ARL Director and an ARL Fellows panel.

This volume of the Summer Student Symposium Proceedings contains many of the selected presentations given at the symposium.

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## **Computational and Information Sciences Directorate (CISD)**

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## Enhanced Experience Replay for Deep Reinforcement Learning

August 7, 2015

**Bryan Dawson**

Senior – University of Maryland Baltimore County  
Computer Science

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### Introduction

**ARL**


- The Army of the future will require many autonomous systems.
- Impossible to build robust systems using hardcoded rules.
- Battlefield environment is dynamic and unpredictable.
- Need to develop adaptive algorithms to handle these challenges.



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**Reinforcement Learning**





- Unsupervised – learning through experience
- Agent develops policy through exploration
- Actions → Consequences
- General learning paradigm



<http://usaircraftpics.blogspot.com/2012/03/rq-11-raven-us-army-unmanned-aerial.html>     [https://upload.wikimedia.org/wikipedia/commons/7/74/Stark\\_contrasts\\_in\\_Afghanistan\\_-\\_080907-F-0168M-01.jpg](https://upload.wikimedia.org/wikipedia/commons/7/74/Stark_contrasts_in_Afghanistan_-_080907-F-0168M-01.jpg)


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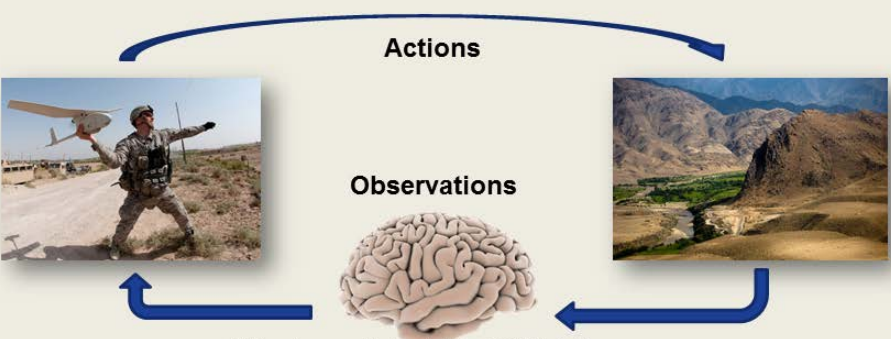



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**Experience Replay**



- Memory of past experiences
- A single experience can improve the policy at any point in time
- Must utilize all information you can gather
- Removes recency bias and reduces variance across updates





<http://tony-wilson.com.au/blog/wp-content/uploads/2010/06/brain-1.jpg>

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## Army = Video Games ?

Army Battlefield Strategy	Video Game
1) Collect data from distributed sensors	1) Collect pixels from game output
2) Analyze data	2) Analyze data
3) Develop/decide on strategy	3) Develop/decide on strategy
4) Take action (troop movement, etc.)	4) Take action (move Mario, etc.)

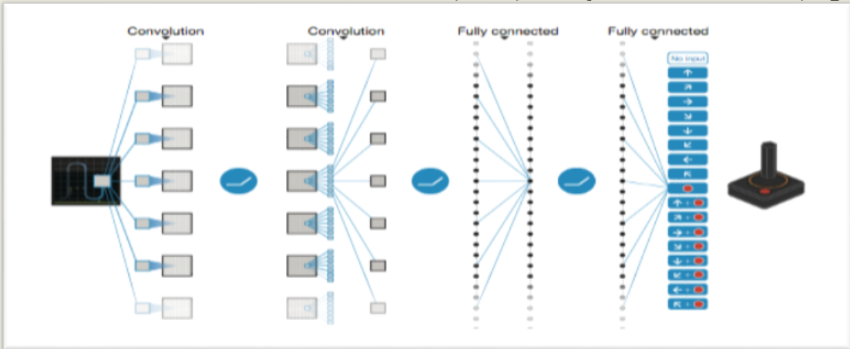

[http://www.mariogames.name/mario\\_image/super-mario-bros-deluxe.jpg](http://www.mariogames.name/mario_image/super-mario-bros-deluxe.jpg)

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## Atari Deep Learning

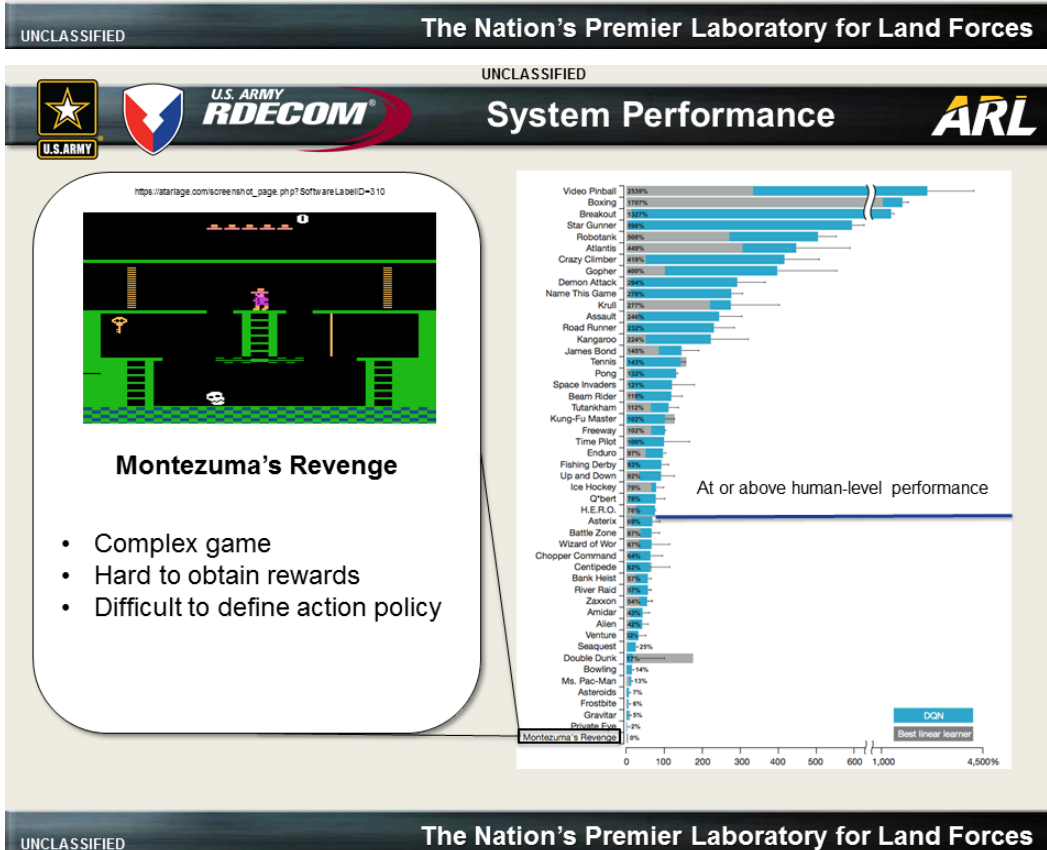
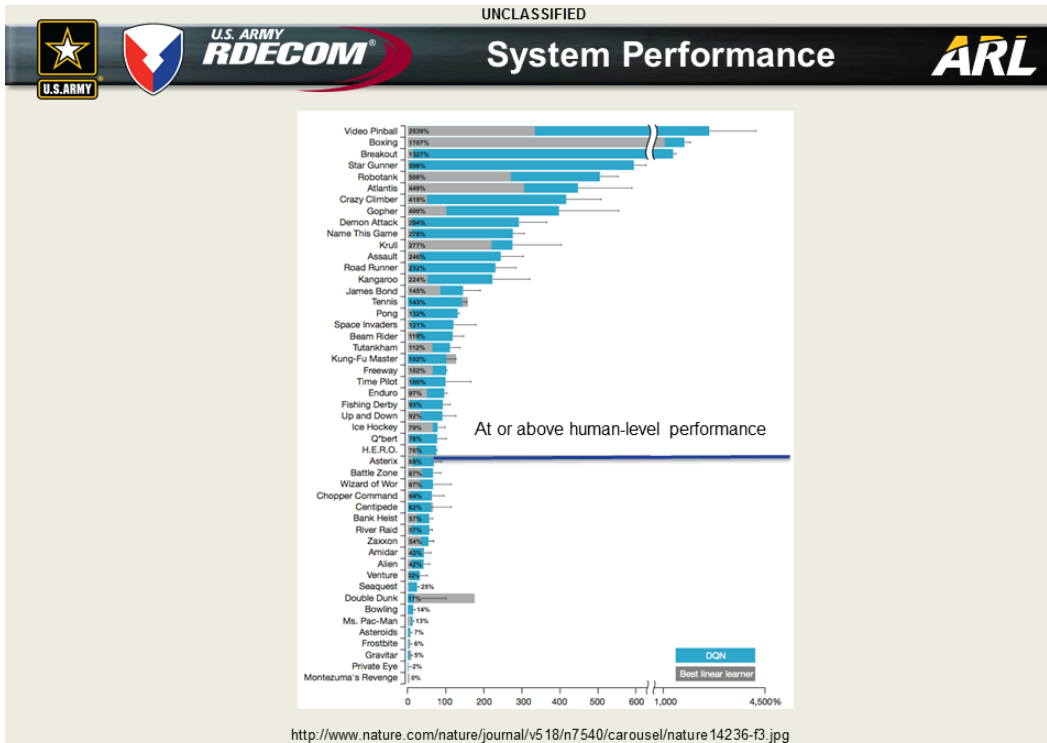
- Uses a convolutional neural network
- Raw frame → expected value of actions
- 10 days of training on 2496 cores!

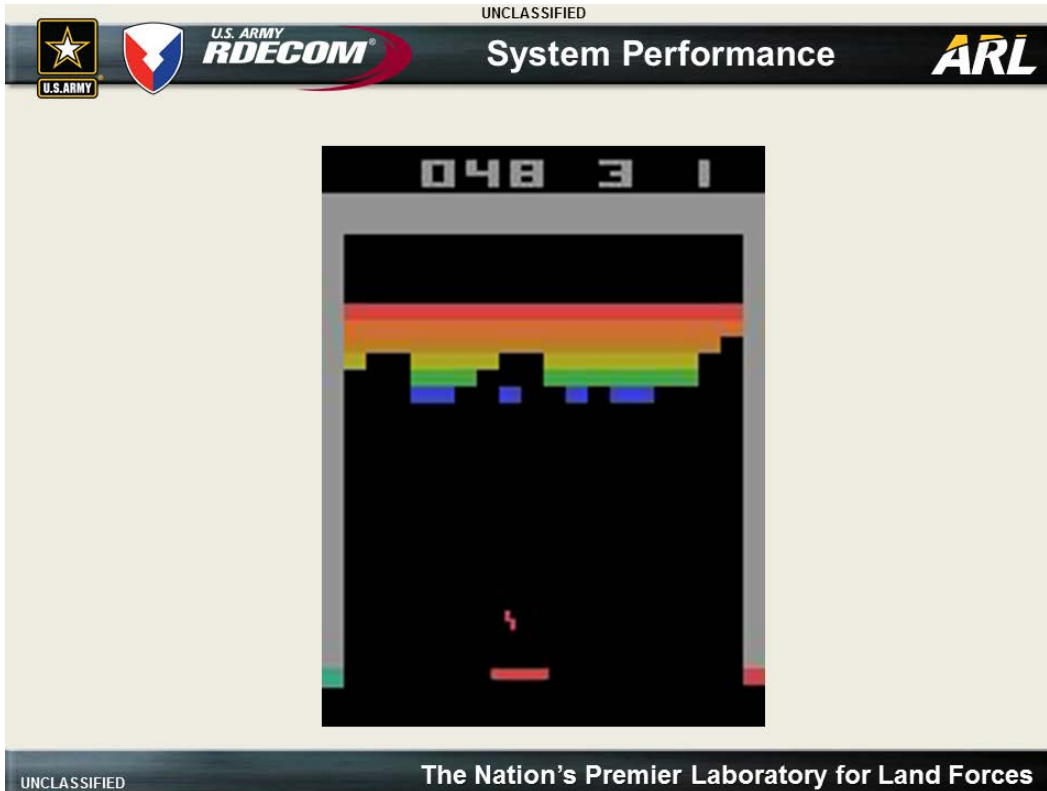
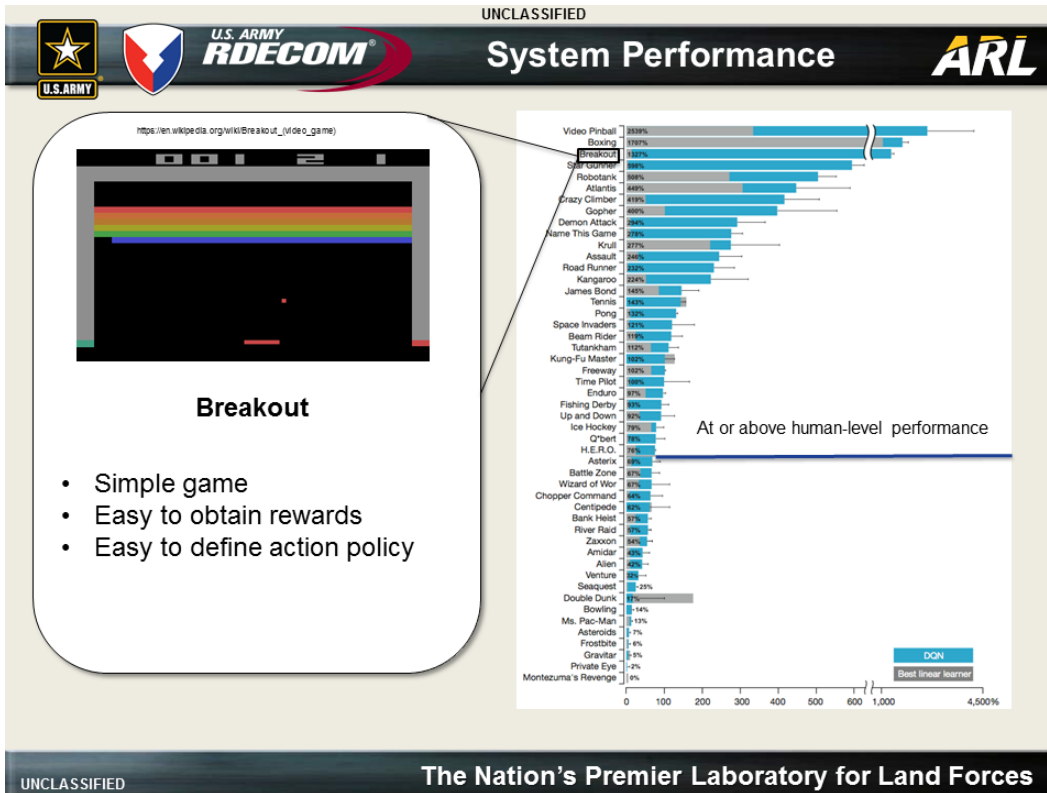
<https://arxiv.org/pdf/1412.0056v1.pdf>

<http://www.nature.com/nature/journal/v518/n7540/carousel/nature14236-f1.jpg>



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## Reward-Biased Replay




**Problem:**

- Default sampling does not emphasize winning.
- Delayed reward signal – hard to correlate actions with rewards.

**Solution:**

- When the agent receives a reward, perform extra policy updates with recent experiences.

Experience	Reward
FRAME ←	★
FRAME ←	⊘
FRAME ←	⊘
FRAME ○	⊘
...	...
FRAME →	★
FRAME ⚙	⊘
...	...
FRAME →	★
FRAME ←	⊘
FRAME ○	★





<http://newsletter.newington.nsw.edu.au/vyvern/files/2014/05/Digital-Brain-1000x440.jpg>


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## Reward-Biased Replay



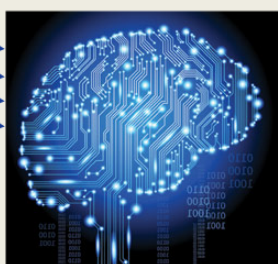
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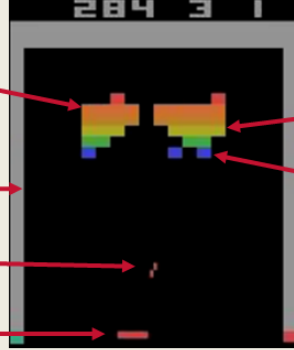
**Representation Pre-training**



**Problem:**



- Agent learns how to represent the game as it learns what to do with those representations.
- Evolving representations negatively affect learning.






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**Representation Pre-training**

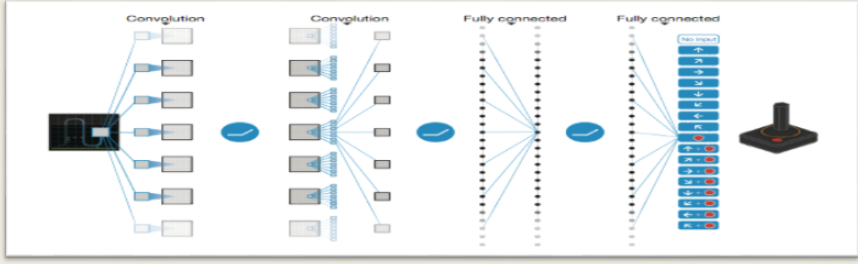


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**Solution:**

- Allow system to train normally until a performance threshold.
- Lock convolutional layers and retrain linear layers from scratch.



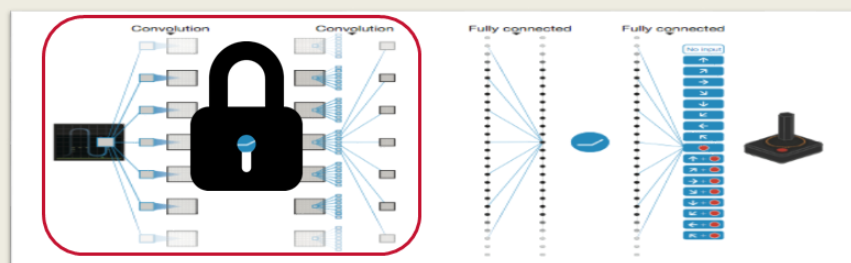
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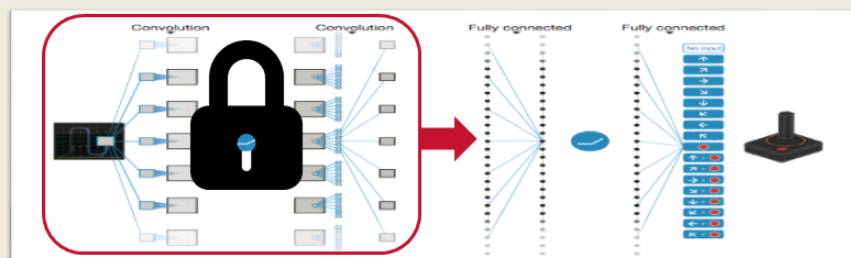


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## Repetition Inhibition

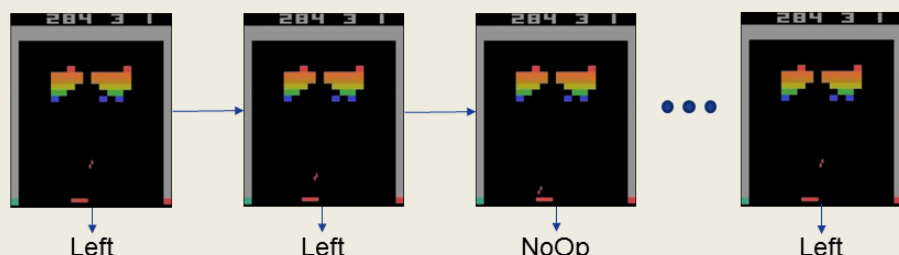


**Problem:**

- Game keeps getting stuck in loops.
- Loops during training can oversaturate replay memory.



**Solution:**

- Examine most recent frames during training.
- If current frame has been seen recently, make random move instead of following policy.
- Break loops and force exploration.




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## Repetition Inhibition




**Problem:**

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### Representation Pre-training

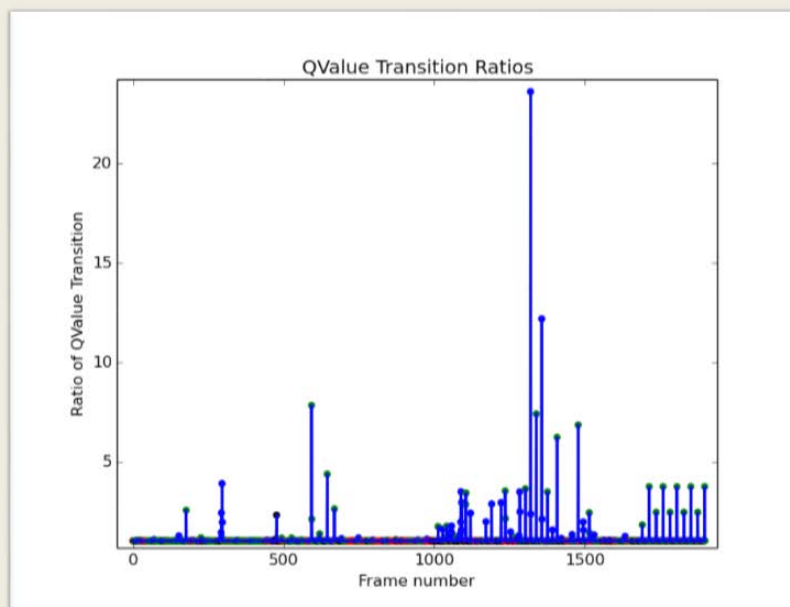
- Achieved reported performance in ONE day of training.
- 10x Speed-up!
- Can test algorithmic adjustments in significantly less time.

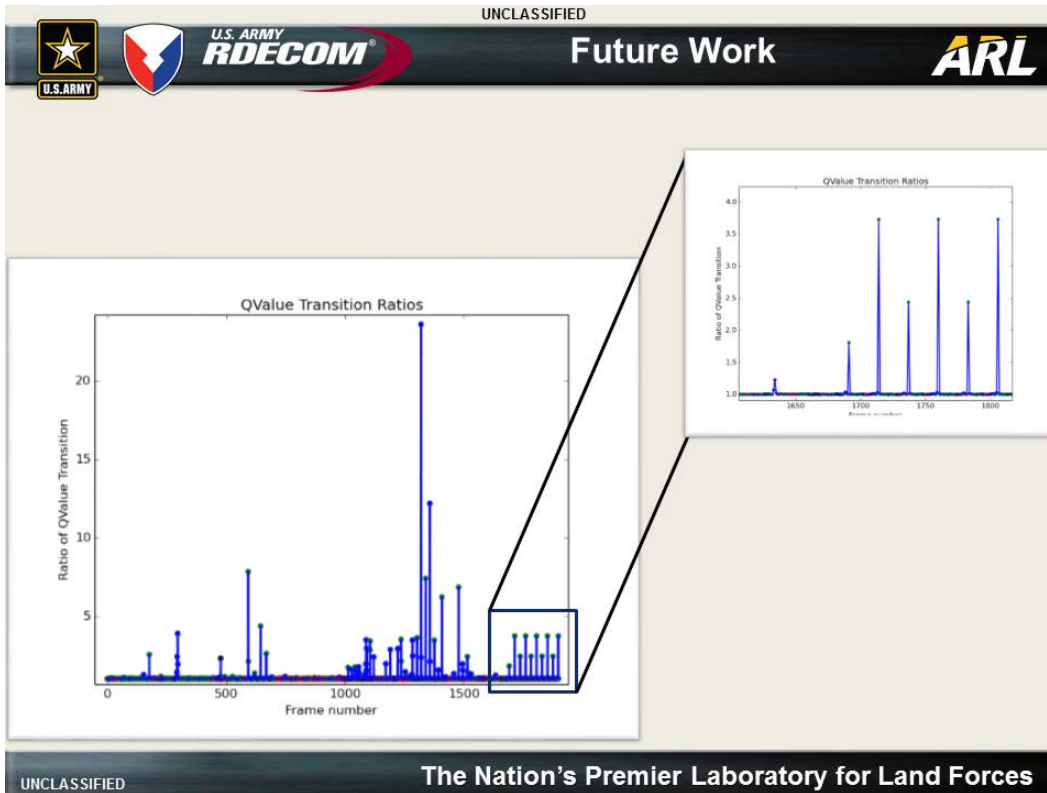
### Repetition Inhibition

- ~50,000 loops were identified and avoided during training.
- Loops still encountered during preliminary testing.



### Reward-Biased Replay

- Successfully sampled actions that triggered rewards.
- Evaluating our results to determine the effect on the system.






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**Path Forward**



- Quantitative analysis of current results
- Investigate scalability of system using additional cores
- Implement additional modifications to system
- Explore collaboration and transition opportunities



[http://www.army.mil/www/pages491/about\\_history/EnvisioningtheArmy/MIG.png](http://www.army.mil/www/pages491/about_history/EnvisioningtheArmy/MIG.png)

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## Acknowledgements



**A sincere thank you to**

- **Dr. David Doria**
- **Dr. Raju Namburu**
- **CISD**
- **Fellow interns**

**Questions?**



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## **Dislocation Density Evolution for FCC Materials Under Shock Loading**

**Presented by: Karoon Mackenchery<sup>1</sup>**

**Advisors: Dr. Rama Valisetty<sup>2</sup>, Dr. Avinash Dongare<sup>1</sup>**

**1. University of Connecticut, Storrs, CT**

**2. Army Research Lab, Aberdeen Proving Ground, MD**

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**Outline**




- 1. Motivation**
- 2. Need**
- 3. Defects in Metals**
- 4. Impact Loading conditions**
- 5. Molecular Dynamics background**
- 6. Specific Objective**
- 7. Computational Details**
- 8. Results**
- 9. Future Work**


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## Motivation





- Materials used for current armored applications possess high yield strengths; however, tend to fail in conditions of **extreme environments** (high velocity impact loading, temperatures, pressures, etc.)
- There exists a need to enhance the properties of next generation of armored materials
  - withstand multiple high velocity impacts
  - retain high yield strengths
  - lightweight
- The design of improved armored materials to be used in extreme environments require **enhanced performance** and **minimal degradation**




1. National Research Council. *Opportunities in Protection Materials Science and Technology for Future Army Applications*. Washington, DC: The National Academies Press, (2011)

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## Need



- Microstructure, chemistry, deformation behavior, degradation behavior all play an important role in the impact (shock) failure of metallic materials.
- For a material under impact loading, failure at the macroscale has been observed to be due to the micromechanical response at the atomic scale, where **nanovoids are generated and coalesce** to contribute to the cracking and subsequent failure of the material.
- In metals, the mechanical behavior is largely determined by the **evolution of defects (twins, dislocations, stacking faults, voids, etc.)**.

Evolution of defect structures determined by a number of factors:

- Microstructure
- Loading conditions
- Temperature of the system
- Pressures



- A need to examine the **contribution of the evolution of defect structures to the failure response in metallic systems under impact loading**

2. A. M. Dongare, B. LaMattina, and A. M. Rajendran, Atomic Scale Studies of Spall Behavior in Single Crystal Cu, *Procedia Engineering* **10**, 3636 (2011).


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## Defects in metallic materials



Metallic materials contain crystal-like structures where atoms are arranged in a certain orientation, then repeated throughout the material

A number of different types of defects located within crystal structure:

-Point defects: interstitials, vacancies

-1-D (linear): **dislocations**

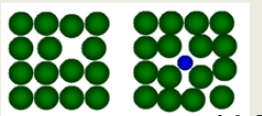
-2-D (planar): stacking faults

-3-D (bulk): voids, impurities

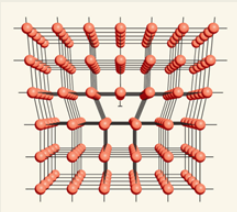
Dislocation Type
Perfect
Shockley Partial
Stair-rod
Hirth
Frank
Twin

*Dislocation Types*

Plasticity within deformed materials due to glide of dislocations throughout material





**Vacancy    Interstitial**




*Example of Dislocation*


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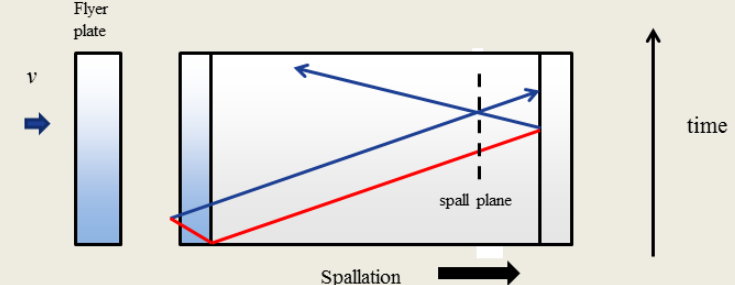
## Impact Loading





Flyer plate

$v$





time

Spallation →

- Experimentally impact loading achieved through plate impact or laser pulse to study shock response of materials.
- Impact generates compressive waves in the flyer plate and target.
- Compressive waves reflect from free surfaces as tensile waves that interact .
- Nucleation of voids, growth, and coalescence to form microscopic cracks and ultimately failure (Spallation).


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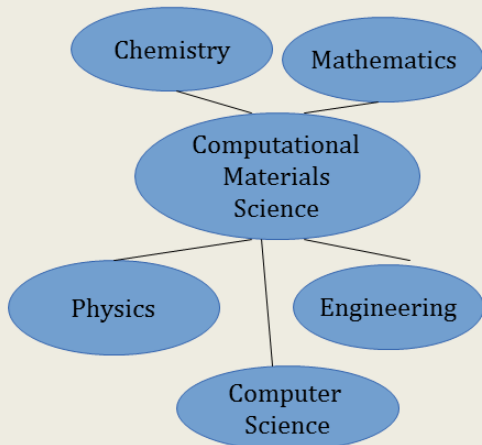



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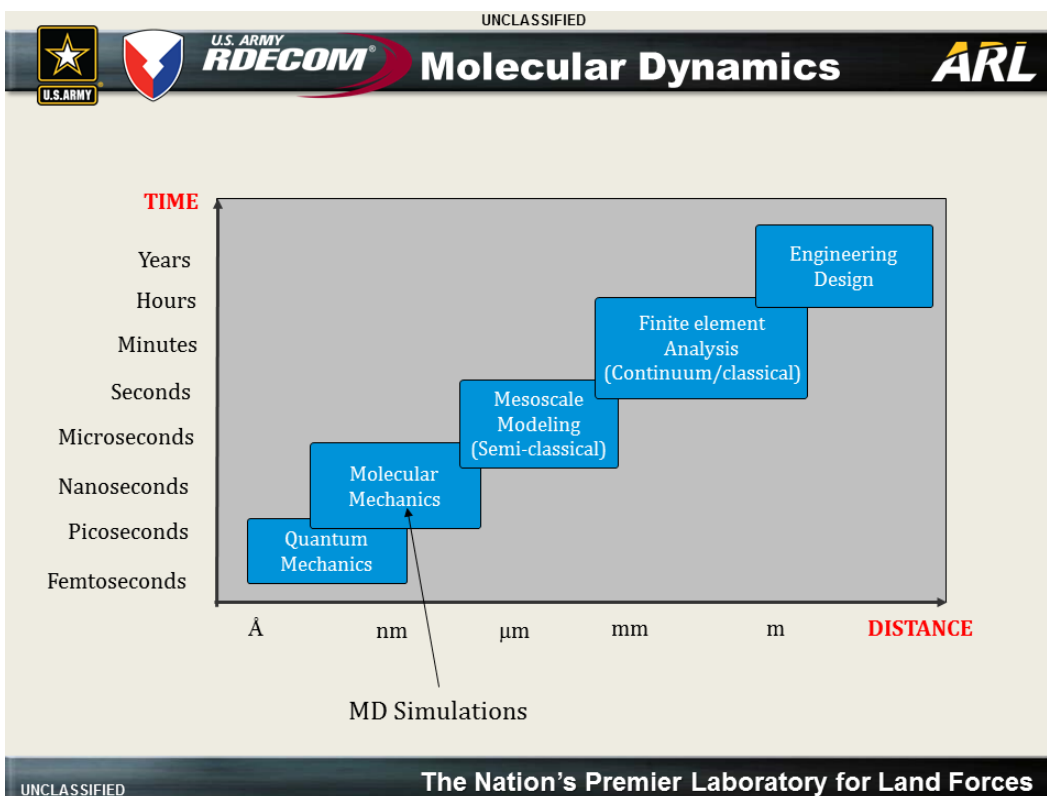
# Molecular Dynamics



- The time and length scales for deformation phenomena (dislocation glide, void nucleation, spall failure, etc.) occurs at the atomic scale.
- Need to utilize computational modeling to view the microstructure as it is deforming.
- Molecular Dynamics (MD) simulations provide the capability to simulate a system of atoms under shock loading.





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## Objective



**Objective: Investigate the effects of the evolution of defect densities on the failure of FCC metallic materials**



- Run large scale shock loading MD simulations for various metallic materials (Single crystal Al, Cu)
- Identify and characterize various types of dislocations present through simulation using *CrystalAnalysis Tool*
- Investigate the relationship between failure, defect evolution, defect type, and other important factors:
  - Material type
  - Microstructure
  - Loading conditions

2. A.Stukowski and K. Albe, Extracting dislocations and non-dislocation crystal defects from atomistic simulation data, *Modelling Simul. Mater. Sci. Eng.* **18**, 085001 (2010)


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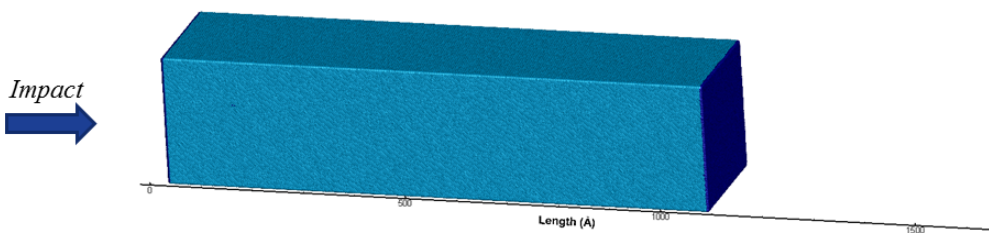
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## Computational Details

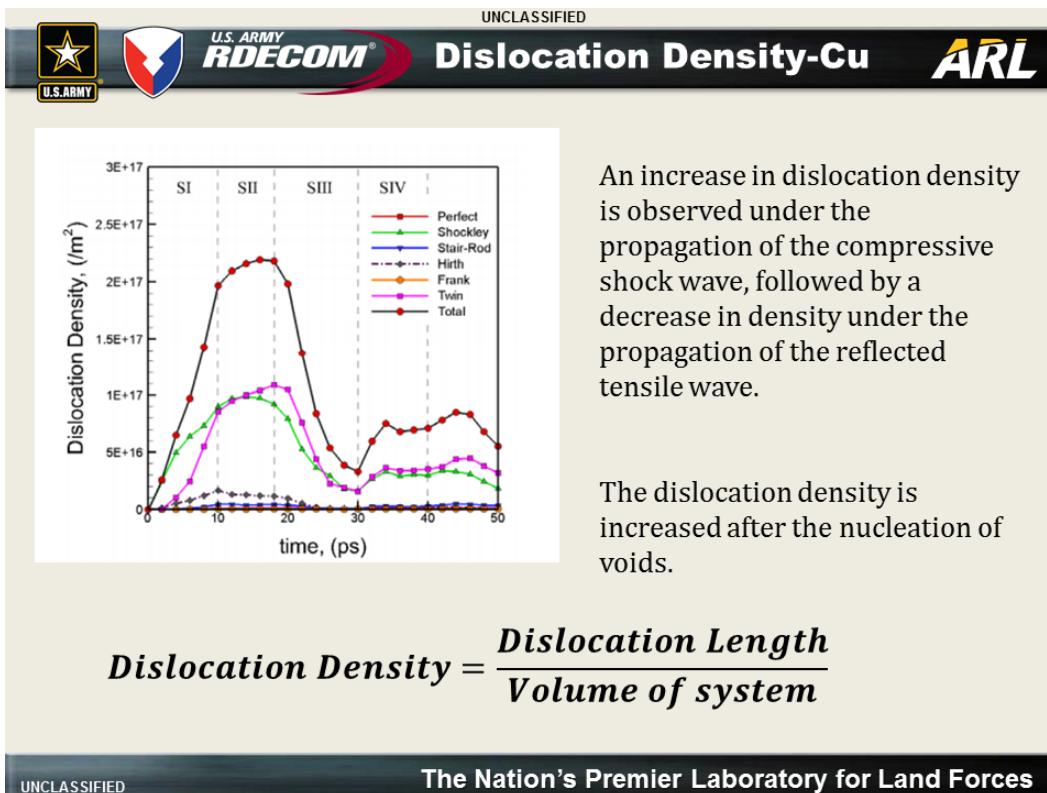
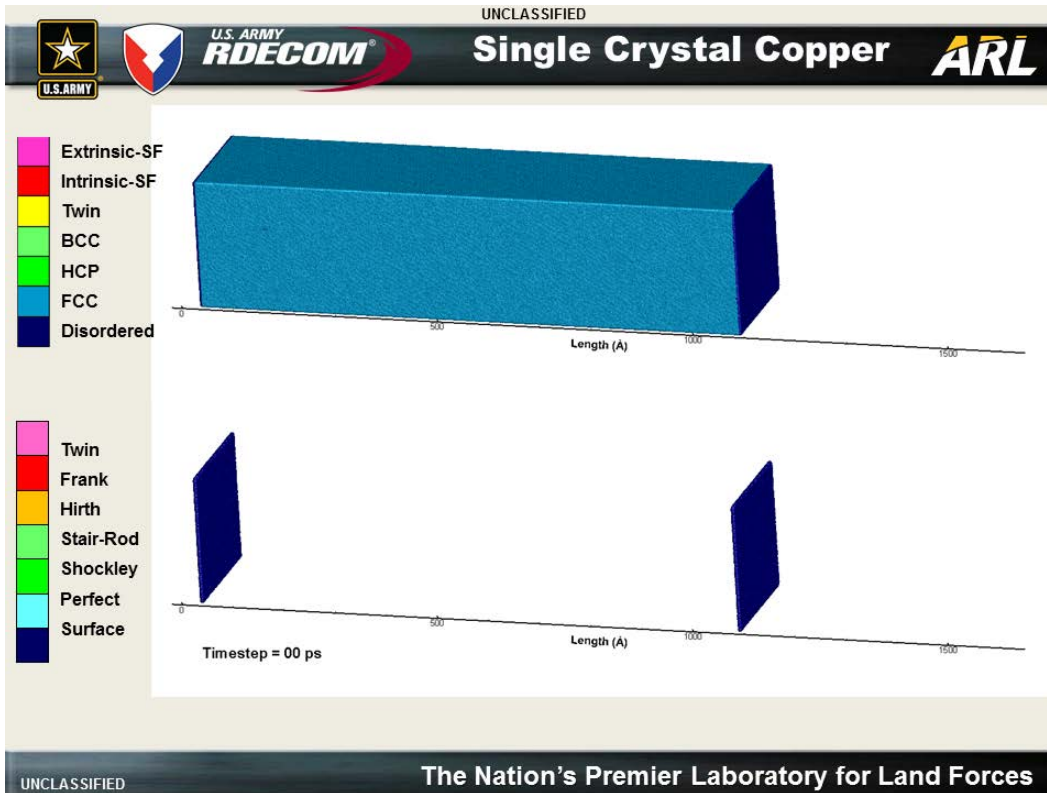


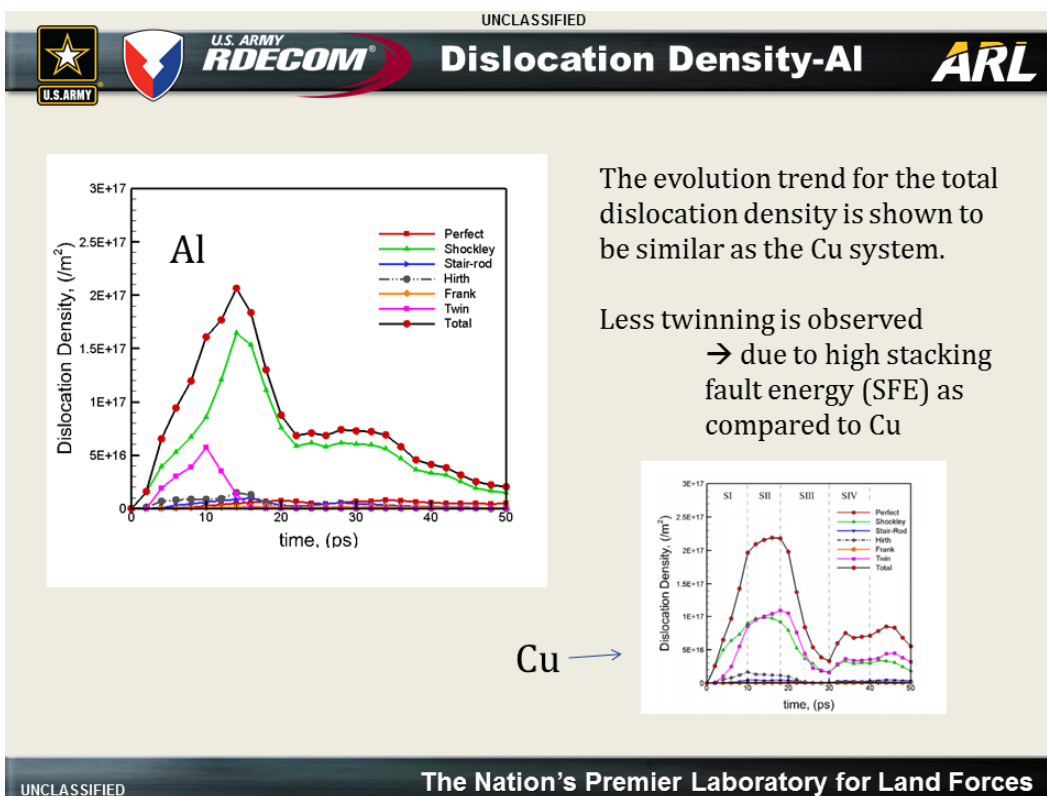
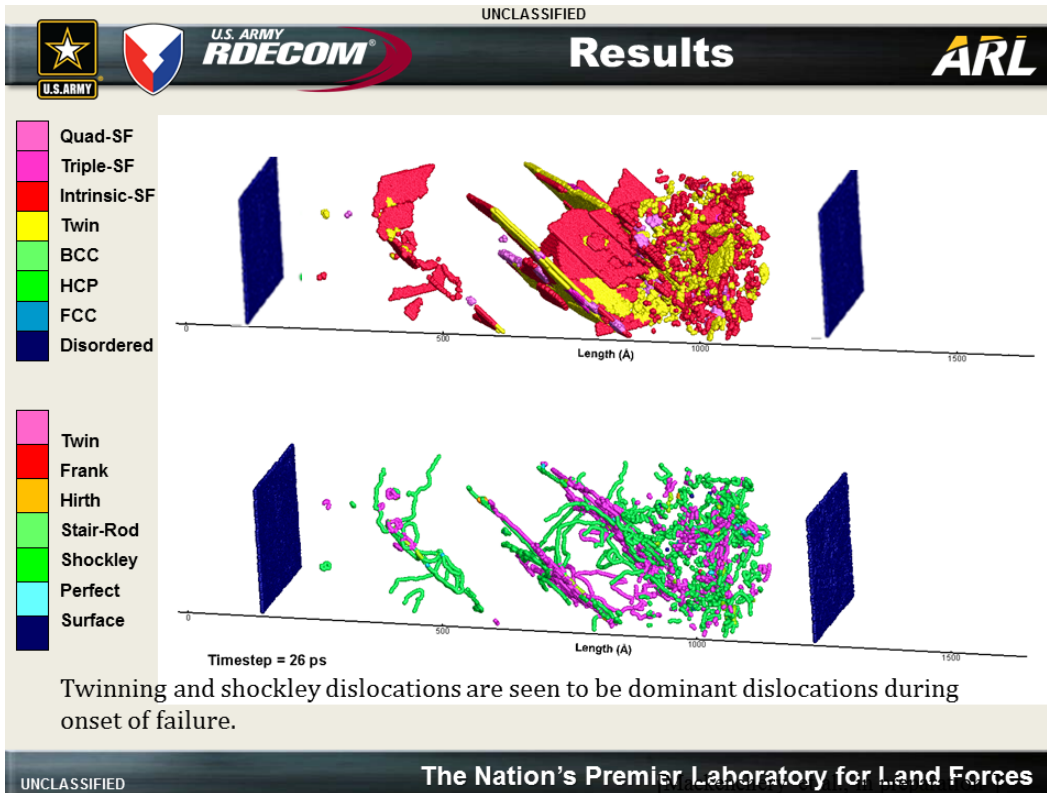


- Create a rectangular box system (long in impact direction) consisting of same type of atoms
- Designate first 3 nm of system as piston
- Provide the atoms in the piston region a constant impact velocity (1 km/s) for a given duration (10 ps)
- Release impact and observe the system evolve as the shock waves travel and reflect within the system
- Post Processing: Characterize different types of dislocations within system




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- MD simulations have been run for single crystal Cu and Al under shock loading simulations
- Dislocations and defects identified and characterized
- Same trend observed for total dislocation density evolution in both systems
- Twinning seen to be one of dominant dislocations in Cu, but not in Al
  - Observed in literature as well

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  **U.S. ARMY  
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Run shock loading simulations and extend dislocation analysis for:

- Different materials and crystal structures (HCP, etc.)
- Larger systems (>1 billion atoms)
- Different loading conditions (impact velocity, orientation, temperature, etc.)
- Different microstructures (nanocrystalline, etc.)

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## **Human Research & Engineering Directorate (HRED)**

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## Effects of Source Accuracy on Present and Absent Targets and Foils

Samantha Harper  
University of Delaware  
August 7, 2015

1

Public Release. Distribution Unlimited.

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Outline

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1. Background
2. Study: Method and Results
3. My Project
  1. Method
  2. Results
4. Conclusions and Future Directions

2


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## Introduction





- **Intelligence Analysis**
- **Trust**
- **Eye Tracking**
  - **Observe search patterns**
  - **Insight into the decision making process**
  - **Examine which types of information are more useful than others**

3


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## Methodology



- **Participants: 13 ARL employees**
- **96 scenes: 4 High Value Targets (HVTs) and 4 Foils**

**Independent variables:**

- **Intel Source Accuracy: 90% vs. 60%**
- **HVT Volume: Number of HVTs described at once (1, 2 or 4)**

**Dependent variables:**

- **Decision Accuracy**
- **Ratings of Difficulty, Confidence, and Trust**
- **Eye movements: number of fixations**



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## Hypotheses



**Trust:**

- Participants will learn that one source is more accurate than the other and trust the accurate source more

**Eye tracking:**



- Individuals will look more often at absent High Value Targets (HVTs) with the 60% Intel Source than the 90% Intel Source
- Individuals will look at absent HVTs and Foils the same amount with the 90% Intel Source

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## Procedure





**Trial:**

- Intel Screen
- Search Screen
- Questionnaire Screen
- Feedback Screen

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Intel Screen



Time: 120

James




1. Present: Blue shirt, Khaki pants

2. Absent: Light hair, Dark jacket

3. Absent: Black top, Wearing a backpack



4. Present: Dark hair, White shirt



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Search Screen





1

2

3

4




Absent  
HVTs:

Submit

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Questionnaire Screen

Use the previous trial for the following ratings

Level of difficulty/complexity of the previous trial

Not Difficult

1

2

3

4

5

6

7

Very Difficult

Confidence in overall decisions about HVTs

Not Confident

1

2

3

4

5

6

7

Very Confident

Trust in the intel given

No Trust

1

2

3

4

5

6

7

A lot of Trust

Submit

Press any key to continue.

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Feedback Screen

James

HVT Number	Intel report	Your decision	Actual
1	Absent	Present	Present
2	Present	Present	Present
3	Present	Absent	Absent
4	Present	Absent	Present

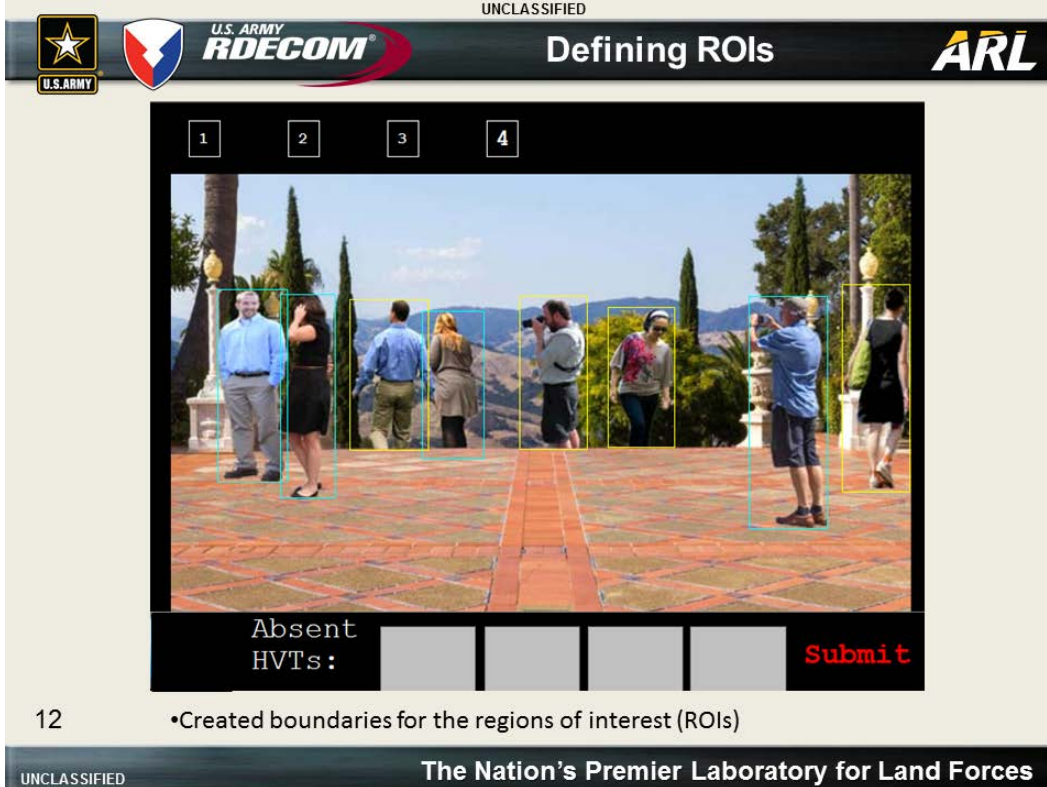
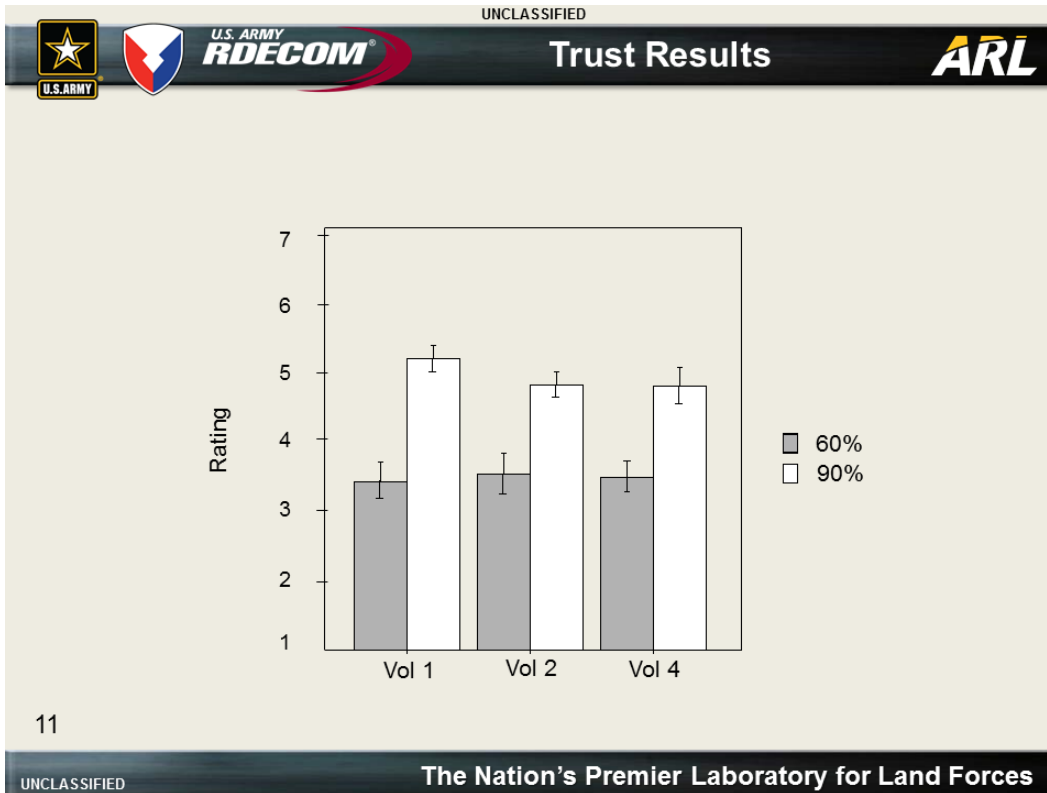
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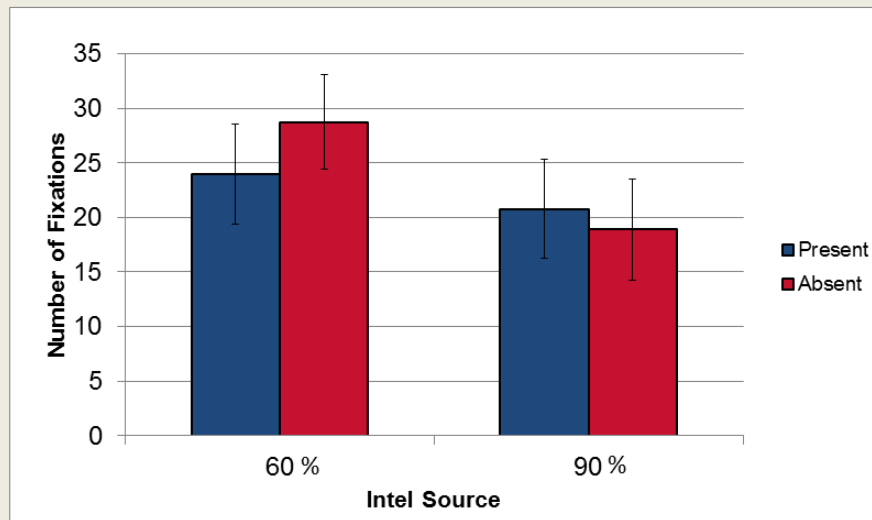
Approved for public release; distribution is unlimited.

37



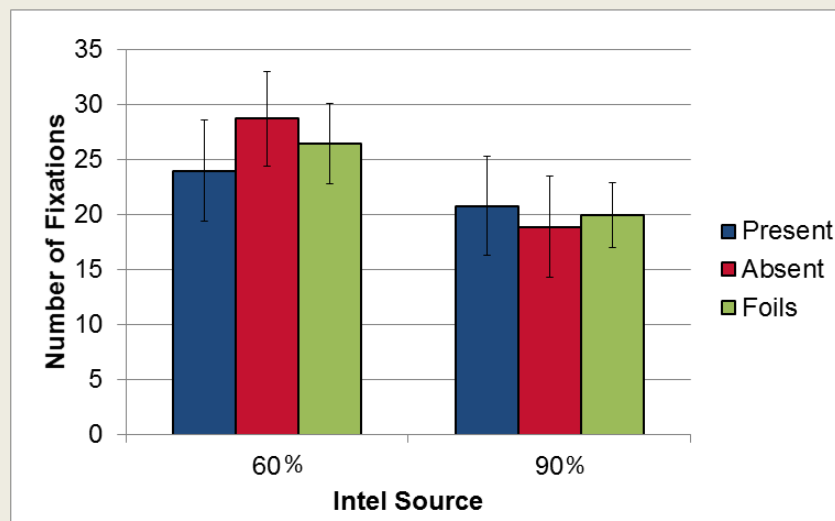
13

- [illegible]



No significant differences, due to small  $n$

15

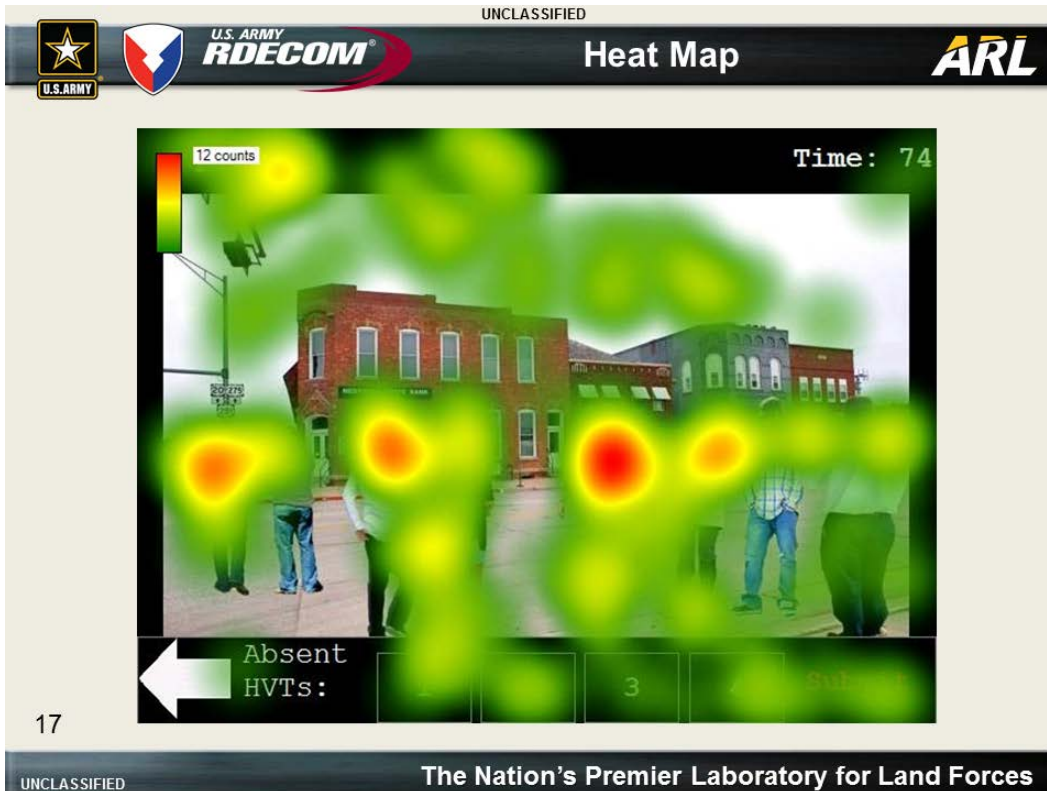


Average number of fixations on Present and Absent HVTs and Foils by Intel source

No significant differences, due to small  $n$

17





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Conclusions

ARL

**Eye tracking:**

- No statistical significance found
- With the 60% Intel Source, participants looked more at absent HVTs than present HVTs
- With the 90% Intel Source, participants looked less at all ROIs, and looked at Foils and absent HVTs less than present HVTs

**Trust:**

- Participants trusted the 90% Intel Source
- Soldiers search more efficiently with trusted sources

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## Acknowledgments



**I would like to thank my mentors Katherine Gamble and Debbie Patton and the Cognitive Sciences Branch.**

**Thank you!**

**Questions?**



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## EFFECTS OF COGNITIVE FATIGUE ON HIGH INTENSITY CIRCUIT EXERCISE

Hope Davis, BA  
Dismounted Warrior Branch

1

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Introduction



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### MY CONTRIBUTIONS:

- Data collection
- Formation of hypotheses
- Data reduction
- Statistical analysis

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Background

ARL

```
graph TD; CP[COGNITIVE PERFORMANCE] --> DM[DECISION MAKING]; CP --> PP[PSYCHOMOTOR PERFORMANCE]; CP --> RI[RESPONSE INHIBITION]; CP --> V[VIGILANCE];
```

Friend et al., 2007; Wilson et al., 2013

**Failures** in cognitive performance can result in increased likelihood of friendly-fire incidents and collateral damage (Wilson et al., 2013).

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Background

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## COGNITIVE FATIGUE

The psychophysiological response to prolonged exposure in a cognitively demanding task results in subjective feeling of "tiredness" and "lack of energy" (Marcora et al., 2009; Pageaux et al., 2014).

Cognitive fatigue can affect subsequent physical performance:



- Time to exhaustion/fixed power (Marcora et al., 2009).
- Timed task/fixed distance (Pageaux et al., 2014).

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**Background**



### WHY SHOULD WE CARE?



- With increasingly sophisticated communication devices, cognitive fatigue may continue to be a relevant issue for the Soldier.
- When cognitively fatigued individuals reach high levels of exertion, they are more likely to disengage from the physical task ([Marcora et al., 2009](#); [Pageaux et al., 2014](#)).
- Soldiers must transition between physically demanding tasks for an extended amount of time, i.e., high intensity circuit training.

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**Hypotheses**



1. Number of overall repetitions completed will be **lower** after completing a cognitively fatiguing task.
2. Time-on-task during the physical exercise will **decrease** after a vigilance task compared to the control task.
3. When separating the 20-minute physical task into quartiles (5-minute segments), time-on-task will be most affected in the **first period** when preceded by the cognitively fatiguing task.
4. Physiological measurements (oxygen uptake and caloric expenditure) will see **no change**.

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Methods

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Seven male and 4 female participants (goal n =30) completed 2 sessions of a vigilance or video (control) task (50 minutes) followed by a timed (20 minute) circuit-workout.

**Vigilance task**

- low Go/ high No-Go (Marcora et al., 2009)

**Video task (control)**

- Documentary (Luxury Trains of the World) used in previous paradigms (Pageaux et al., 2014).

**Physical Task**

- 20 minutes, as many repetitions as possible
- Circuit of 5 pull-ups, 10 push-ups and 15 squats

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Methods

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Methods





- Data Reduction
  - Total repetitions was calculated.
  - Time-on-task (TOT) was measured in seconds with video observation.
  - TOT was also separated into four 5-minute segments within the circuit exercise task to examine time effects of the vigilance task.
  - Mean value of oxygen uptake and caloric expenditure calculated.
- Statistical Analysis
  - Repeated measures t-tests determined differences between cognitive tasks for repetitions, TOT, and physiological measurements.
  - Repeated measures ANOVA examined effect of time and the vigilance task on TOT.


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Results

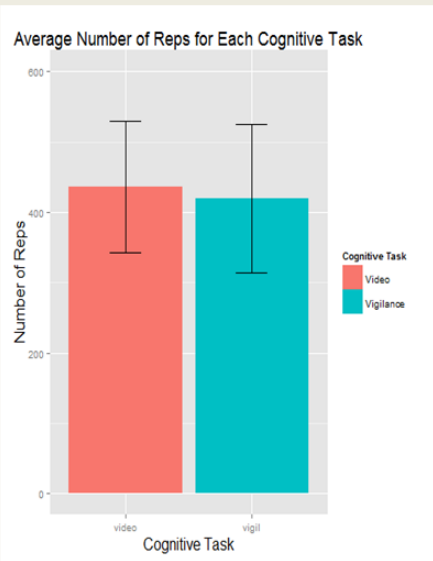


### REPS vs. COGNITIVE TASK

Contrary to the hypothesis, there was no significant difference in the total number of reps between cognitive tasks ( $p = 0.18$ ).

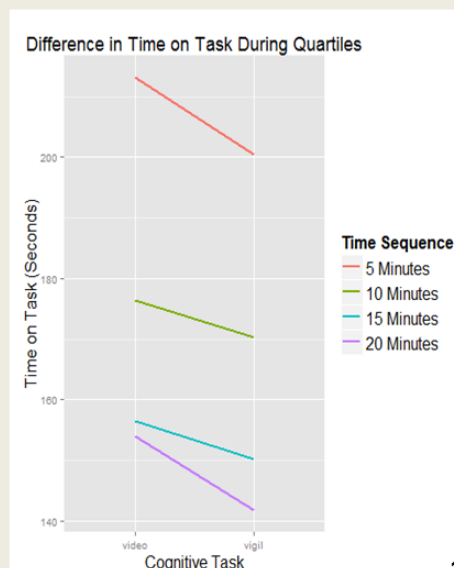
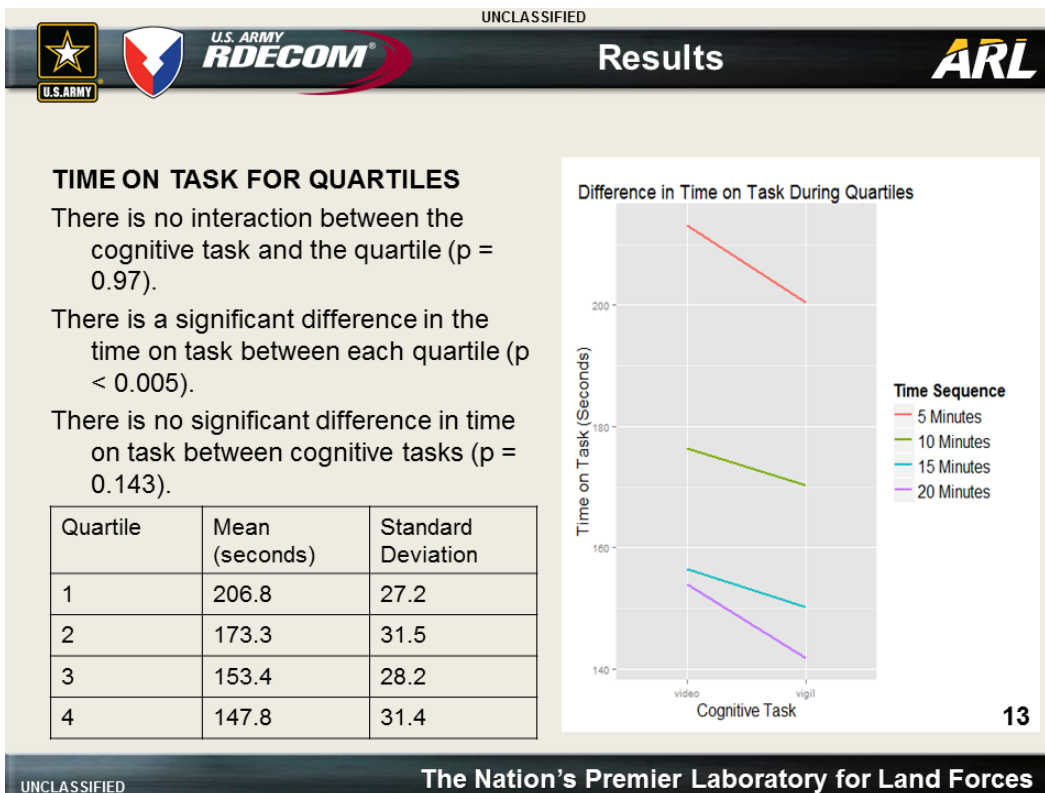
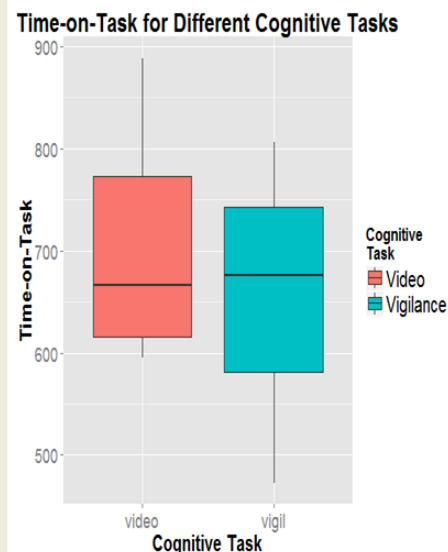
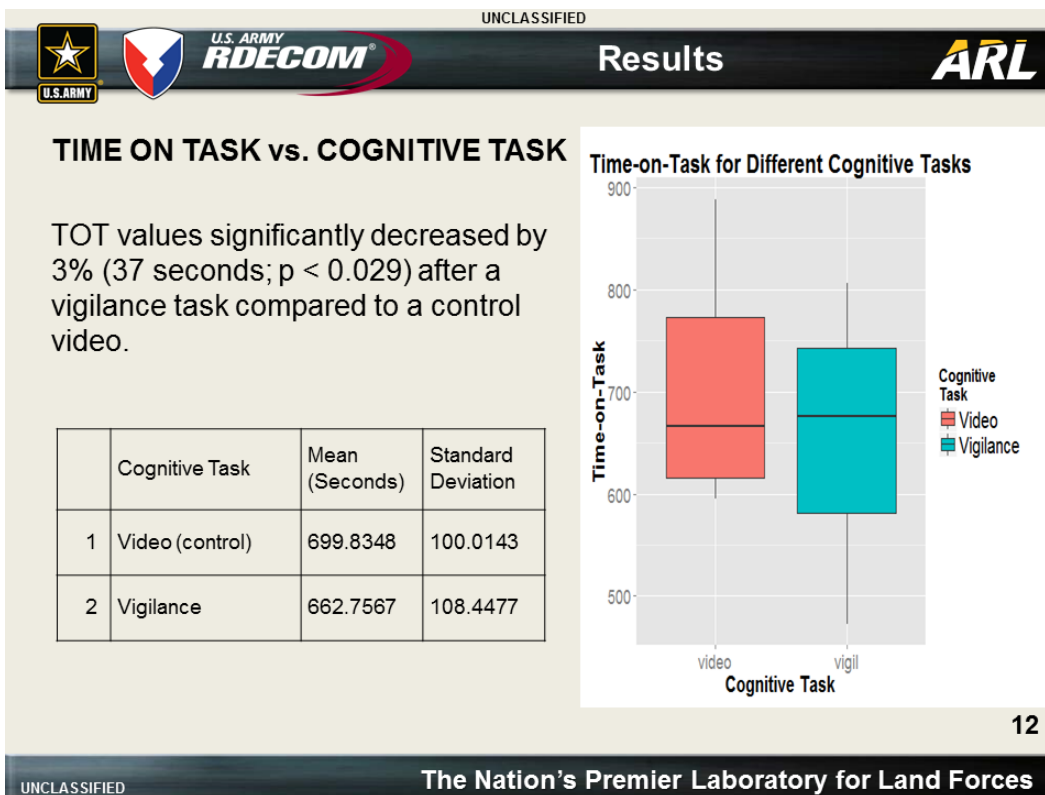
Cognitive Task	Mean (Reps)	Standard Deviation
Video (control)	436	93
Vigilance task	420	106

Average Number of Reps for Each Cognitive Task

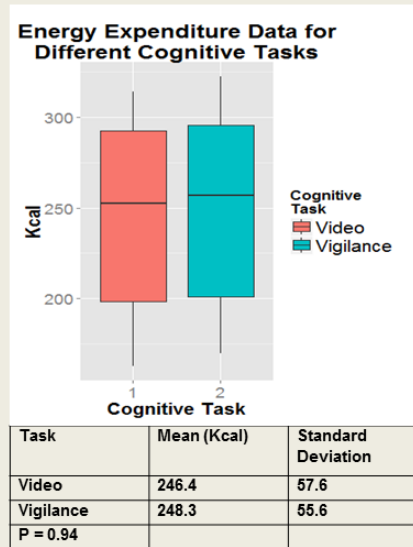
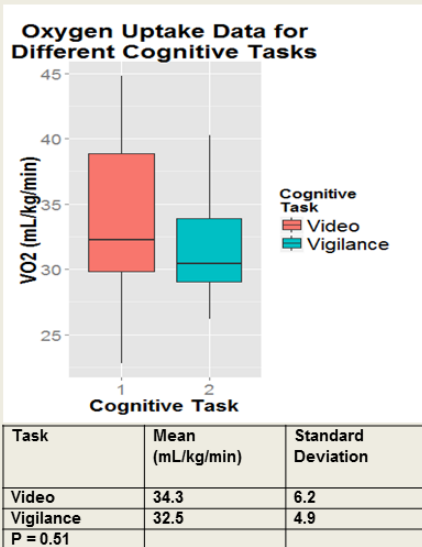


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### PHYSIOLOGICAL DATA



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So far, the circuit task demonstrates that performance is decreased by 3%.

Similar to findings in past literature:

- 6% increase in timed run (Pageaux et al., 2014 )
- 15% decrease in time to exhaustion (Marcora et al., 2009)

The discontinuous nature of the present study is potentially more operationally relevant than constant stretch-shortening-cycle tasks performed in previous studies.

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**Future Research**



## **COGNITIVE PSYCHOLOGY**

Dr. Head's ongoing study examines the effects of cognitive fatigue on subsequent marksmanship in Soldiers.

## **PHYSIOLOGY**

1. Creating a technique to mitigate effects of cognitive fatigue in Soldiers in the field (automated devices).
2. Sex differences in response to stress (progesterone during menstrual cycle).
3. Changes in biomechanics/predisposition to injury.

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**CITATIONS**



Friedl, K. E., Grate, S. J., Proctor, S. P., Ness, J. W., Lukey, B. J., & Kane, R. L. (2007). Army research needs for automated neuropsychological tests: Monitoring soldier health and performance status. *Archives of Clinical Neuropsychology*, 22, 7-14.

Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Physiology*, 106, 857-864.

Pageaux, B., Lepers, R., Dietz, K. C., & Marcora, S. M. (2014). Response inhibition impairs subsequent self-paced endurance performance. *European Journal of Applied Physiology*, 114, 1095-1105.

Wilson, K., Head, J., & Helton, W. S. (2013). Friendly fire in a simulated firearms task. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 57, 1244-1248.

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## Acknowledgements



The author wishes to acknowledge the mentorship of Dr. Matthew Tenan and Dr. James Head.

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## **Sensors and Electron Devices Directorate (SEDD)**

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U.S. Army Research, Development & Engineering Command

## Bio-Hybrid Fuel Cells for Waste Mitigation



**TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.**

**Marcus Benyamin**  
University of Maryland, College Park  
Junior, Chemical Engineering & Mathematics

**Mentors: Dr. David Mackie & Dr. Justin Jahnke**  
BioTechnology Branch

(U//FOUO) **07 August 2015**



### Objective & Outline



**Summer Objective: Design, build, and test a flowing vapor-fed bio-hybrid fuel cell system for wastewater treatment**

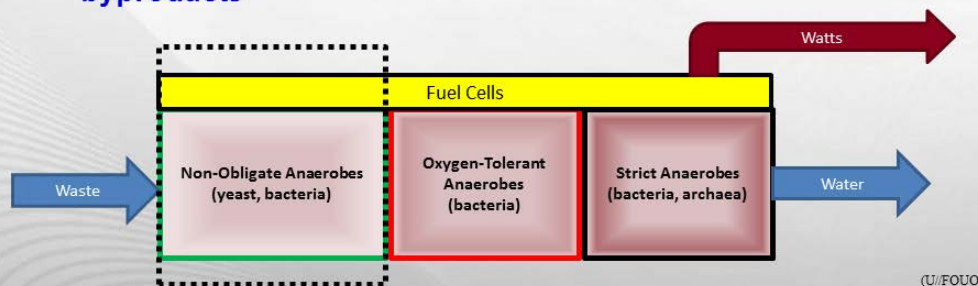
- **Introduction**
  - Army Motivation
  - Direct Ethanol Fuel Cells and Bio-Hybrid Fuel Cells
- **Design of System**
  - Setup
  - Predictions and Testing
- **Results**
  - Kinetic data, flow rate data, and reactor model
  - Power vs. Voltage
  - Long-term operation of BHFC system
- **Conclusions and Future Work**

(U//FOUO)

- **Waste to Water and Watts (WWW) for the Forward Operating Base (FOB)**
  - **Requirements: Small scale, mobility, stealth, low-energy**
- **Microbial Processing of food waste**
  - **Multi-stage processing generates clean water and chemicals/fuel as byproducts**

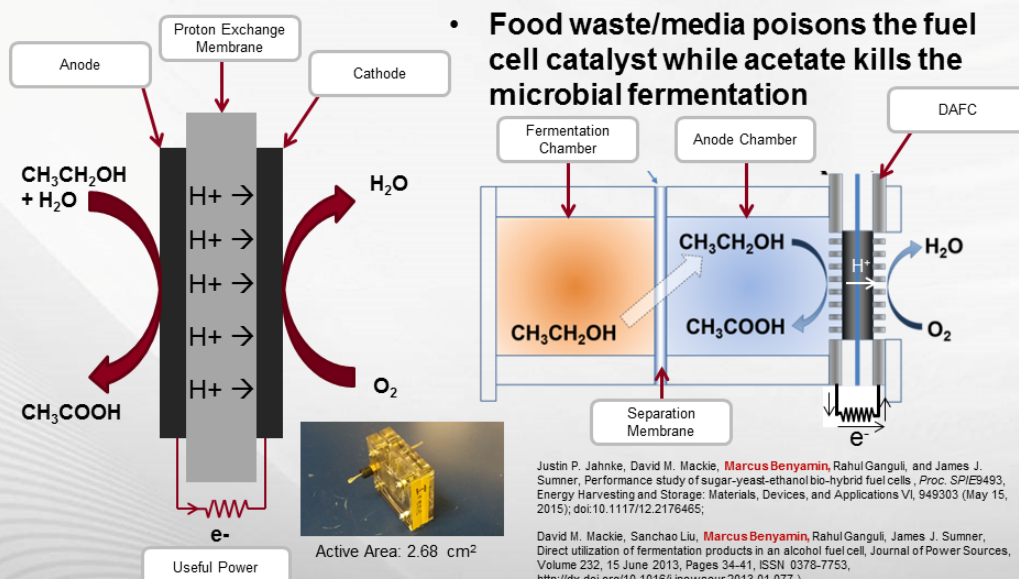


Photo Credit: Karen Parrish, DoD



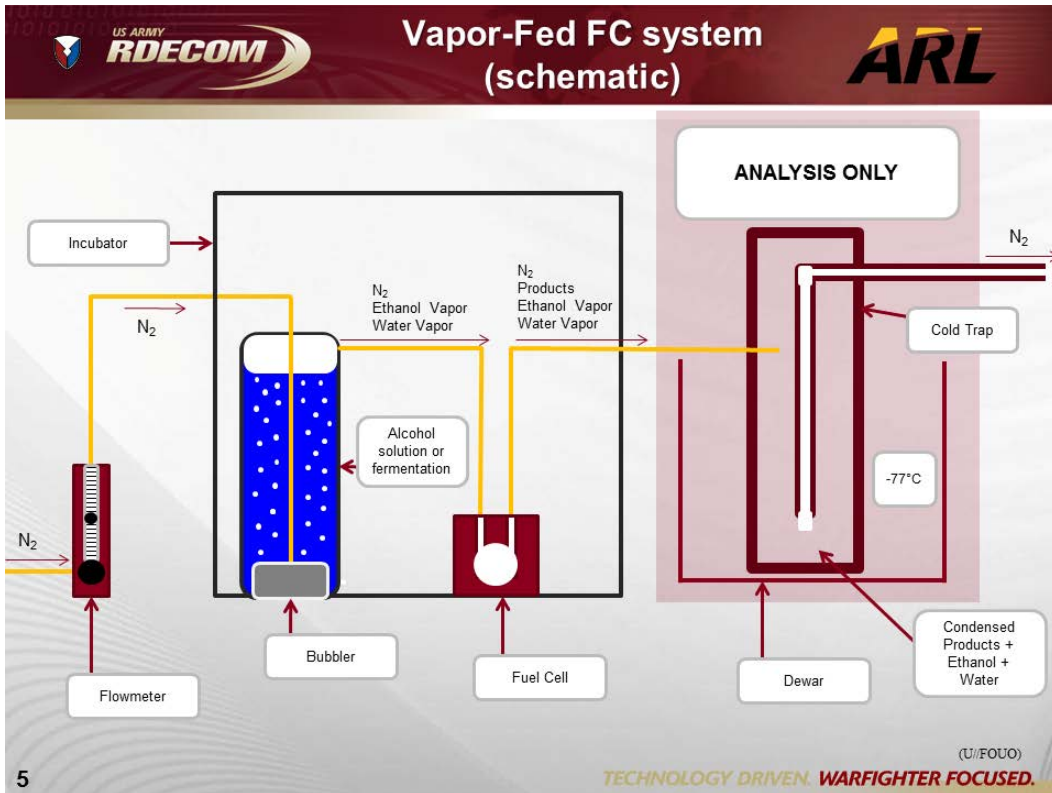
(U//FOUO)

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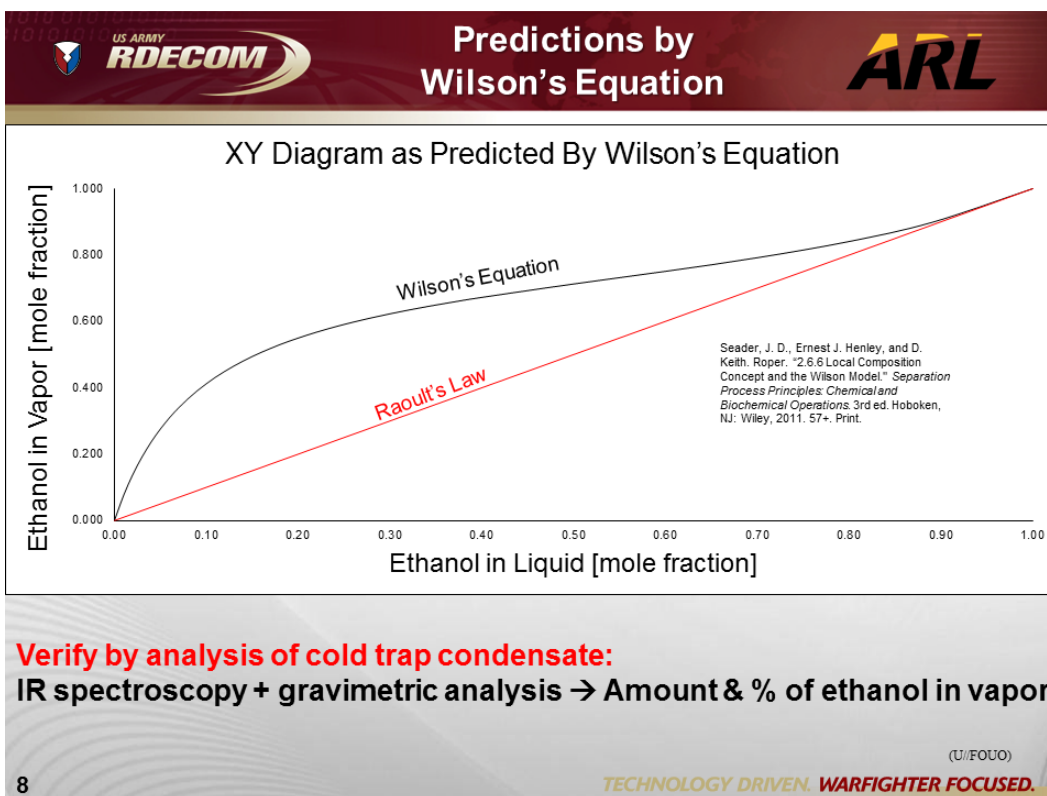
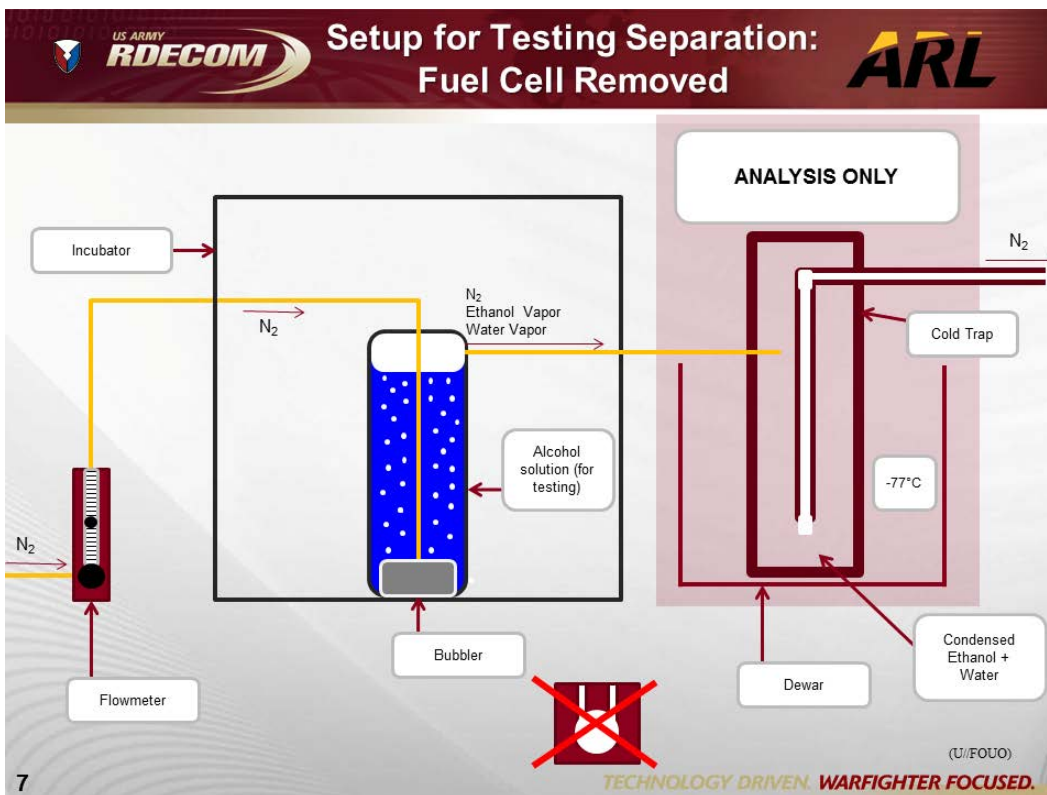


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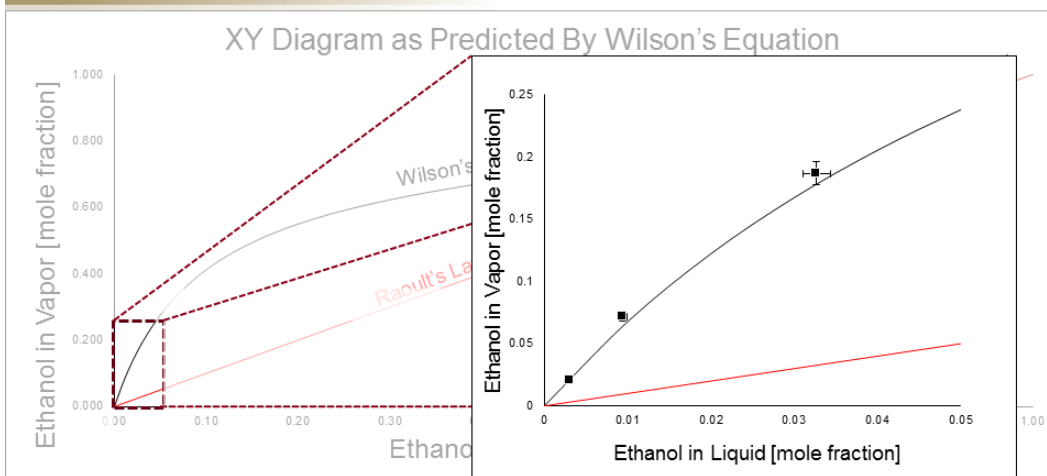
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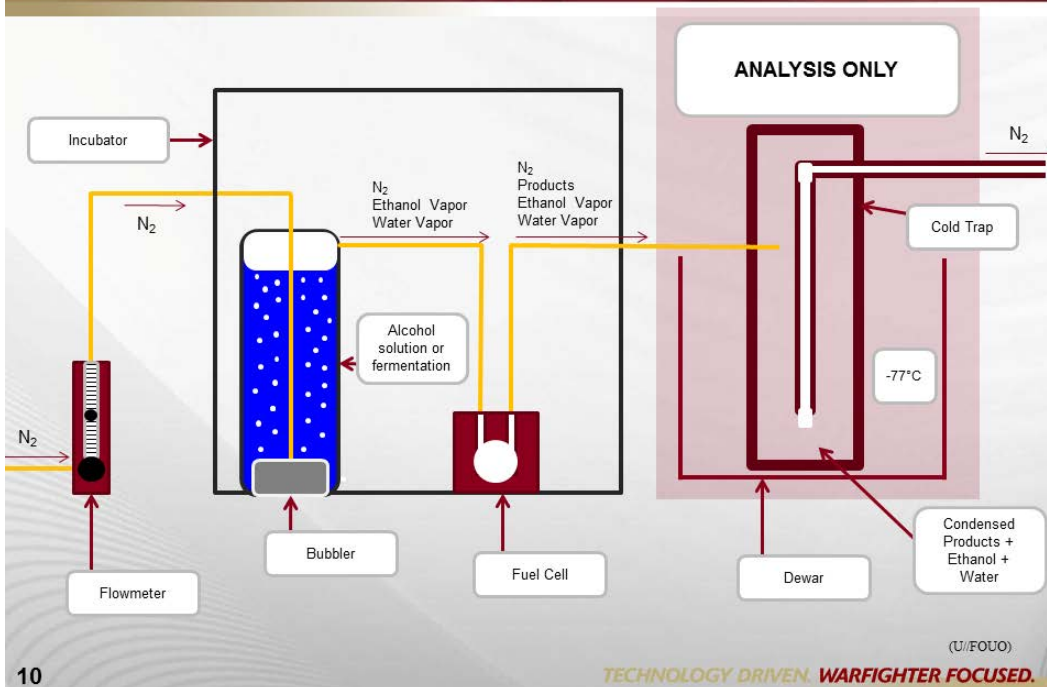
Verify by analysis of cold trap condensate:

IR spectroscopy + gravimetric analysis → Amount & % of ethanol in vapor

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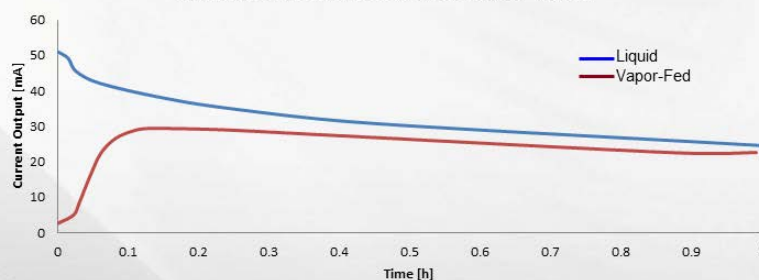
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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Combining analysis of condensate and electrochemical data, we can:

- Calculate a mass balance for the fuel cell to determine crossover losses
- Examine product distribution at varied voltages and temperatures
- Determine conversions for ethanol

I-t Curve for 3%EtOH, Liquid and Vapor



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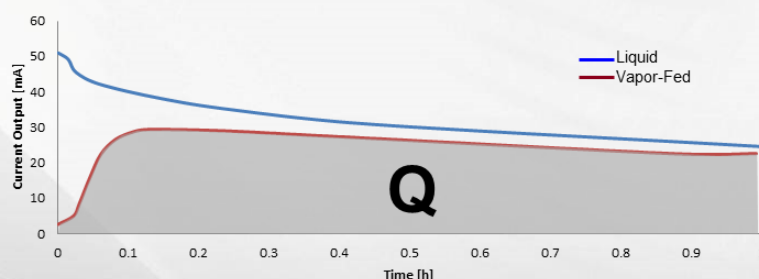
(U//FOUO)

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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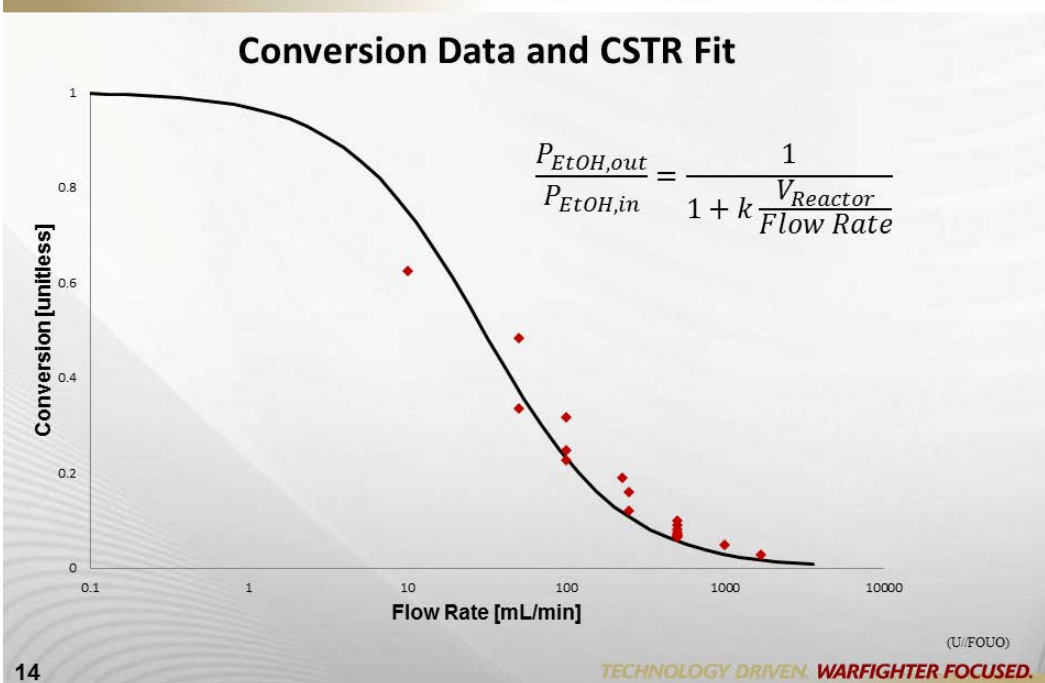
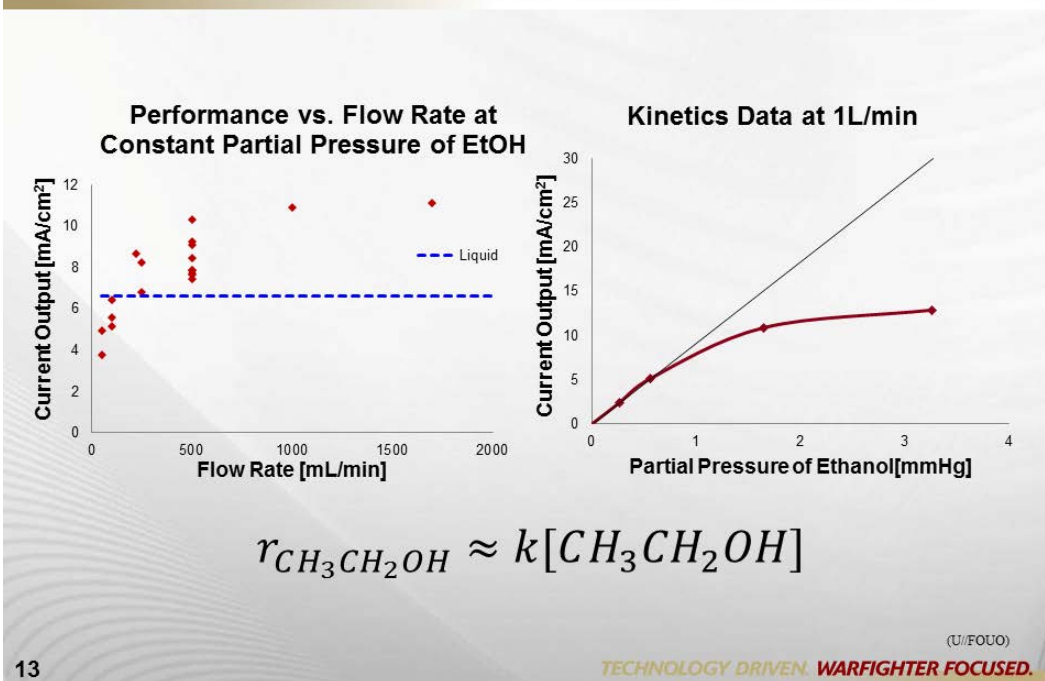
$Q \rightarrow \# \text{ electrons} \rightarrow \# \text{ moles reacted} \rightarrow \% \text{ conversion \& mass balance}$

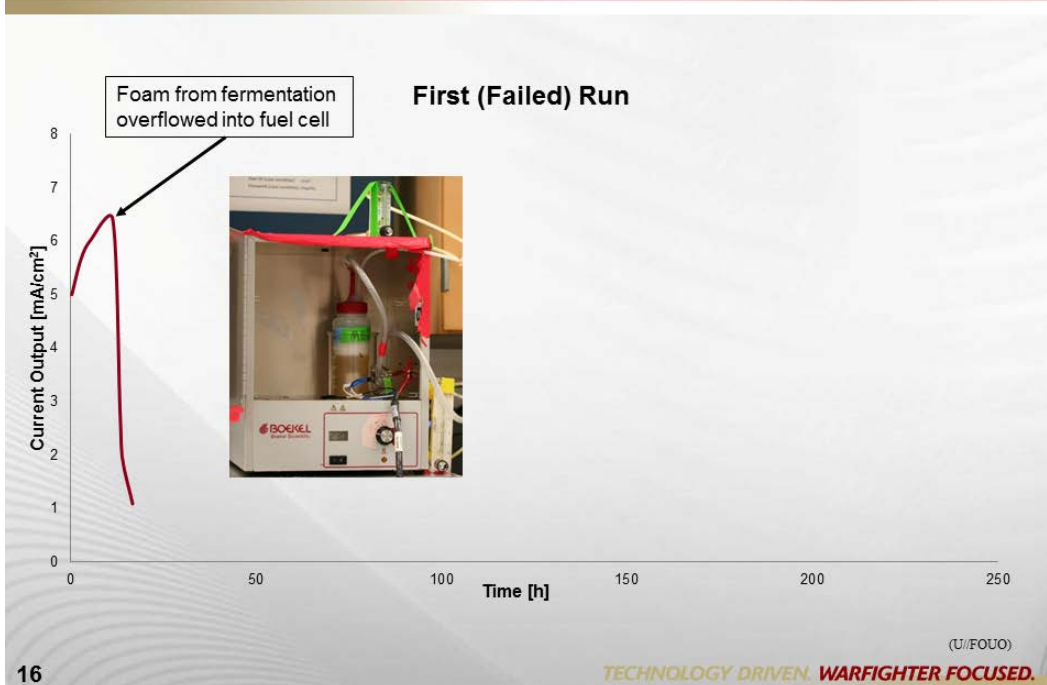
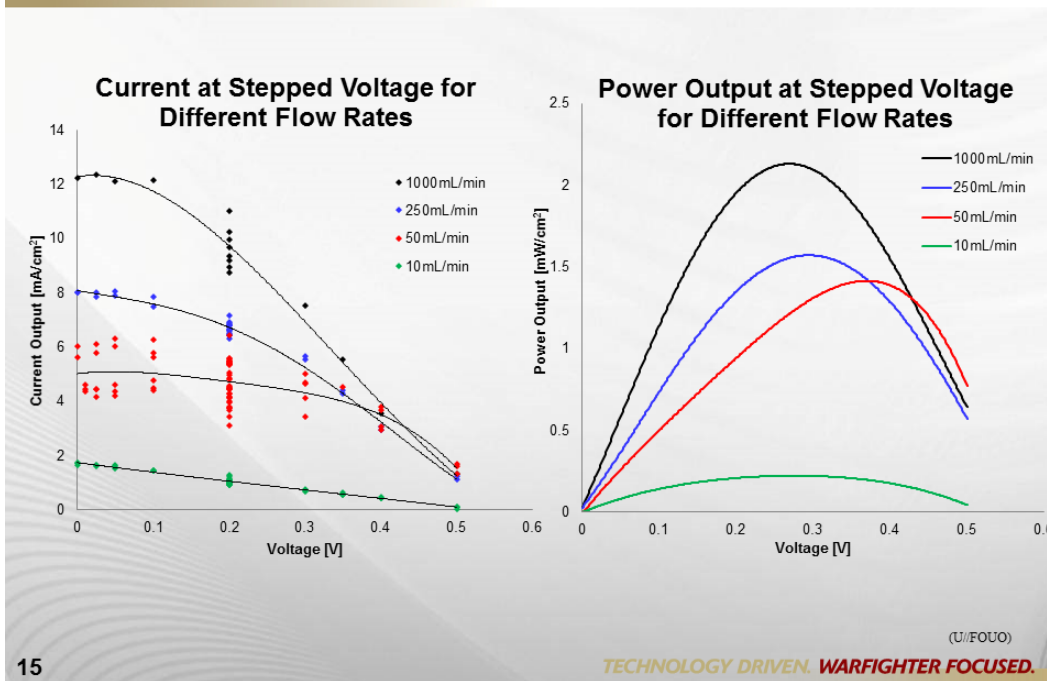
Most of performance data can be taken with only the electrical measurements.

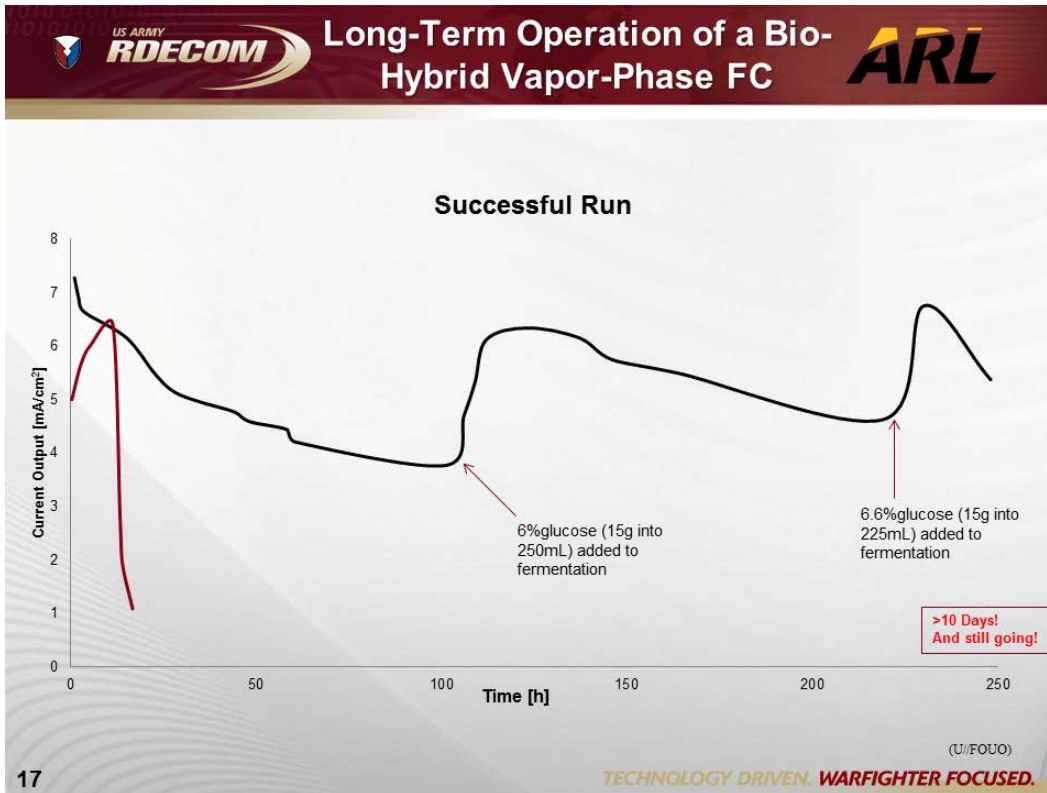
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US ARMY RDECOM Conclusions and Future Work ARL

### Conclusions:

- Built and tested a novel vapor-fed bio-hybrid fuel cell
- Performance is comparable to that of liquid-fed fuel cell
- Flow rate and performance data fit to CSTR reactor model
- Optimal voltage for peak power output depends on flow rate
- Extended BHFC run time from <24 h to 2 weeks

### Future Work:

- Kinetics and product distribution at elevated temperature
- Lower-energy vapor generation
- Microbial consortia to digest simulated food waste

### Acknowledgements:

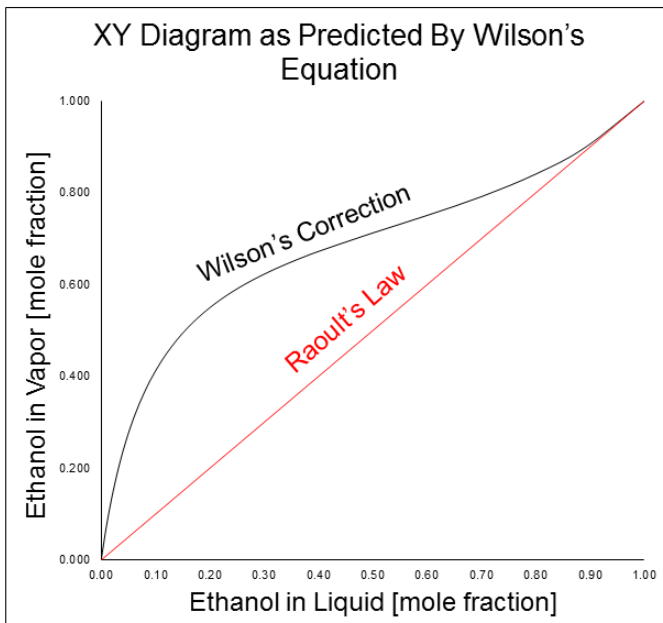
- Dr. David Mackie and Dr. Justin Jahnke
- Dr. Jim Sumner and the Biotechnology Branch

18 • ARL, ASEE, and CQL

(U//FOUO)

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.





**Raoult's Law**  
 $y_a P = x_a P_a^{sat}$

Wilson's Correction  
 $y_a P = x_a \gamma_a P_a^{sat}$   
 $\gamma_a = \gamma_a(T, x_a)$

(U//FOUO)

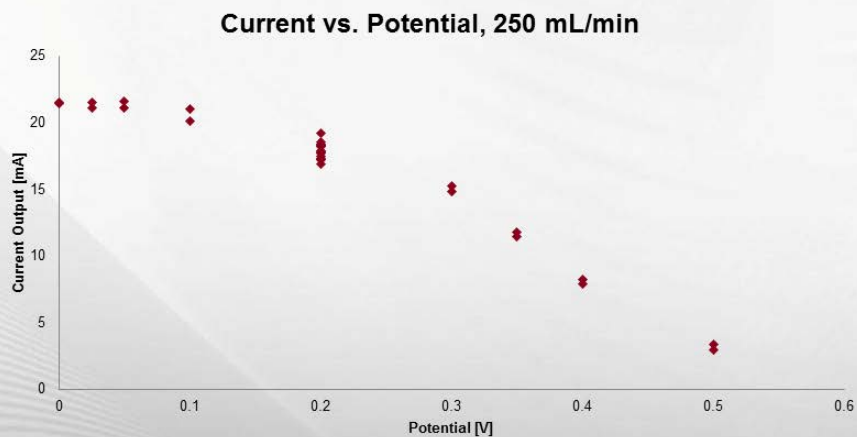
$$r_{CH_3CH_2OH} \approx k[CH_3CH_2OH]$$

- For Langmuir Adsorption:

$$r = \frac{kK_{EtOH}P_{EtOH}K_W P_W}{[1 + K_{EtOH}P_{EtOH} + K_W P_W + K_{CH_3CHO}P_{CH_3CHO} + K_{AcOH}P_{AcOH}]^2}$$

(U//FOUO)

- Fuel Cell has intrinsic variability in performance
- Operating at “standard conditions” before varying parameters reduces variability



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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

- Cold trap condensate compared to I-t data
- Results:
  - Yield of acetic acid was nearly quantitative with current output
  - <5% of product was  $\text{CH}_3\text{CHO}$  and  $\text{CO}_2$
  - Loss of ethanol through the PEM can be bound to <10%

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## Accelerated Lifetime Testing on Porous Silicon

Sauradeep Sinha, 1<sup>st</sup> summer

Junior Chemical Engineering major at UMD

Mentor: Dr. Nick Piekiet

July 27, 2015

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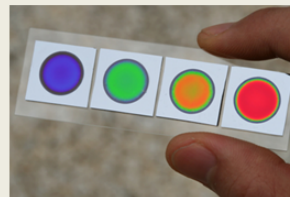
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Porous Silicon

**ARL**

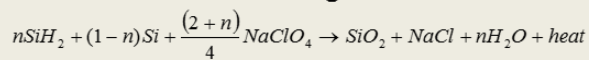
### Overview:

- Porous Silicon (PS) is a high surface area (>900 m<sup>2</sup>/g) material, formed from bulk silicon (Si)—most common substrate for MEMS and electronics.
- Typically has nanometer scale pore size
- Small pores and high surface area make it attractive for a number of applications including solar cells, biosensors, or energetic materials.

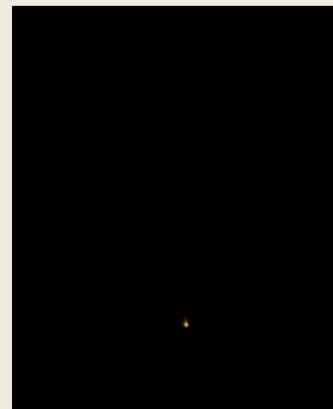


Sailor Research  
Group, University  
of California, San  
Diego

### Porous silicon as an energetic material:



- Porous silicon + oxidizer (**NaClO<sub>4</sub>**, MgNO<sub>3</sub>, sulfur, etc.) = high energy density system
- Highly tunable reaction rate
- Rapid combustion (3600 m/s) possible
- Low energy initiation, 10's of μJ



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## Galvanic Etch Method

HF-based electrolyte

$\text{Si}_3\text{N}_4$

PS

holes

Si

Pt

$\text{H}^+ \quad \text{H}_2\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightarrow 2\text{H}_2\text{O}$

Galvanic Electrochemical Etch: Ionic charge reduction at the Pt cathode, oxidation at the Si anode, current is self-generated

$\text{Si}_3\text{N}_4$  acts as an etch mask in HF

Max: 511.01 kV Spot: 4.1 nA Power: 10.00 mW Scale: 10.00 um Date: 9 Jan 2013

WD: 5.0 mm ZPos: 10.00 um Name: Porous Silicon Prod: Aug Scale: 10.00 um

*Energetic Nanoporous Silicon Devices,  
L.J. Currano, W.A. Churaman*

- Easily patterned on-chip
- MEMS compatible fabrication
  - allows easy integration of PS as an on-chip energetic

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## Motivation

**Application:**

- Fuzing and initiation
  - Initiator for thermal batteries (ManTech Project, in collaboration with ARDEC)
  - MEMS Safe and Arm Initiator (collaboration with ARDEC)

**Problem:**

- These applications require long lifetimes—up to 20 years
- Little work on understanding aging and the total lifetime of PS
  - In the news: Pyrotechnic inflator system failures in air bags

**Focus:** Determine lifetime and gain better insight into the long term chemical nature of PS



**PS-Initiator/Thermal Battery:**

**MEMS Safe and Arm Initiator**

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**Sample Fabrication**



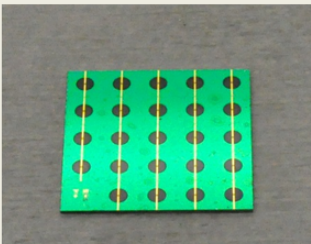
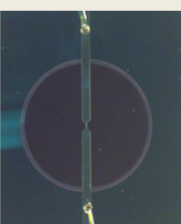
Start with basic silicon wafer with a protective nitride layer and platinum (cathode for etch).

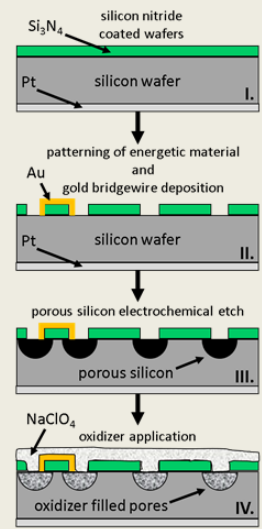
Selectively etch nitride (DRIE) to pattern in a design and apply gold bridgewires through sputter deposition.

Place in hydrofluoric acid solution for porous silicon etch.

Singulate 2 mm PS regions and electrically connect them to a dual in-line package.

Oxidizer was added to the pores and dried.








Approximately 300 devices have been tested.


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**Experimental Methods**

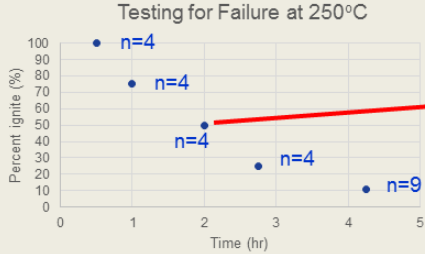


### Accelerated aging tests

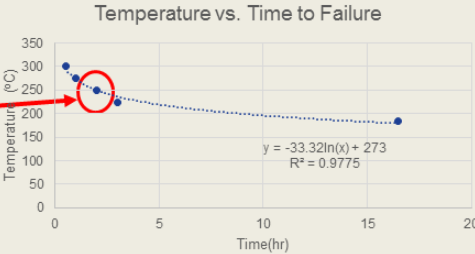
Samples are aged by baking at a specified elevated temperature and electrically ignited at low voltage for set intervals of time until failure point is reached.

- Needs to last 20 years
- Accelerated lifetime tests
  - High temperature, heat to failure, mimics long term conditions

Testing for Failure at 250°C



Temperature vs. Time to Failure

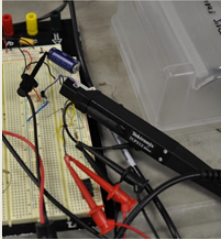



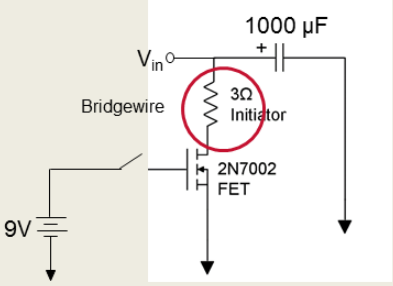
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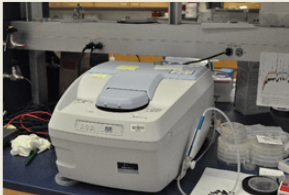
## Experimental Methods

- Electrical testing: Recorded current and voltage through the bridgewire during ignition
  - Measure power, energy and time to burst when devices are electrically ignited.



- Differential Scanning Calorimetry (DSC):
  - Analyze endothermic and exothermic events of PS along a temperature profile.



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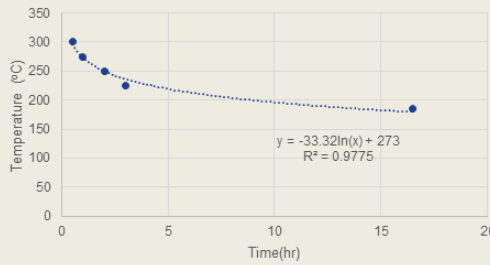
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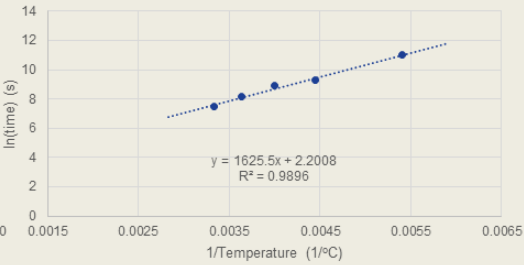
## Failure Times

Determination of failure times, which are the time points when at least 50% of the packaged devices do not ignite at a given temperature

Temperature vs. Time to Failure



Arrhenius model of time to failure varying with temperature



Arrhenius Equation from NIST Handbook:  
 $\ln(t_f) = (\Delta H / k T) + \ln(A)$

**Number of devices tested:** At least 20 devices were tested per experiment at a specified temperature  
**Estimated lifetime at 20 °C using Arrhenius model:** 23 years

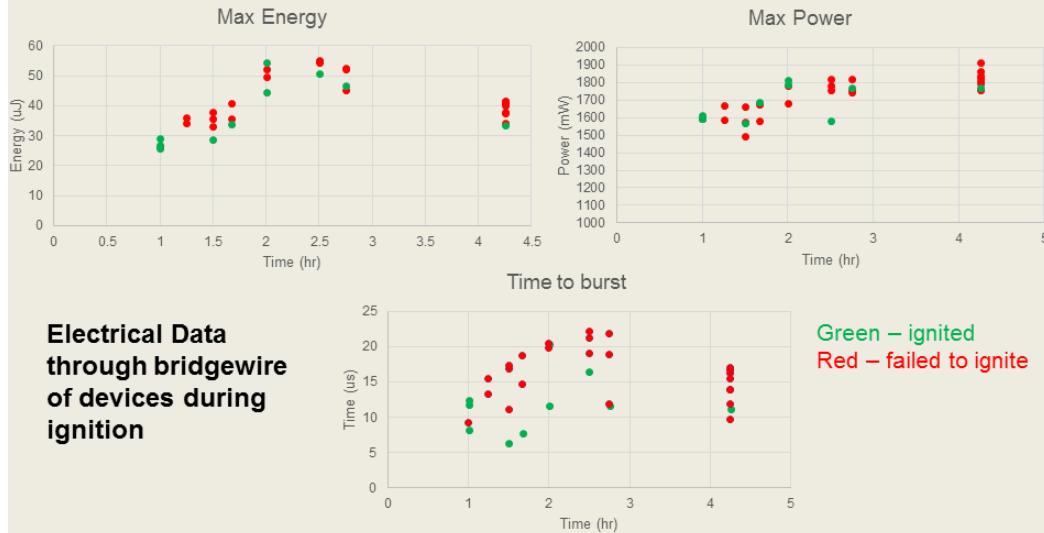
*What is causing failure?*

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Concerned with bridgewire failing due to aging

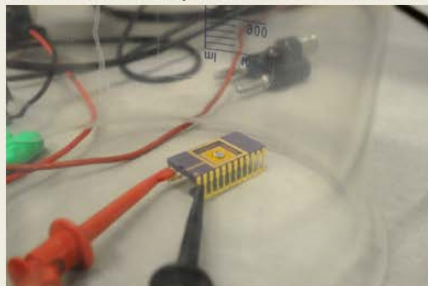


Takeaway: These graphs show that the bridgewire and electrical connections are not failing during aging.

Electrical ignition not causing failure

- Failure must be due to chemical reaction between porous silicon/ $\text{NaClO}_4$
- Qualitatively observe reduced performance during aging

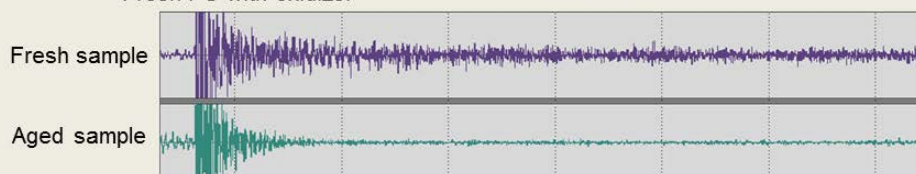
Videos of PS samples with a handheld DSLR

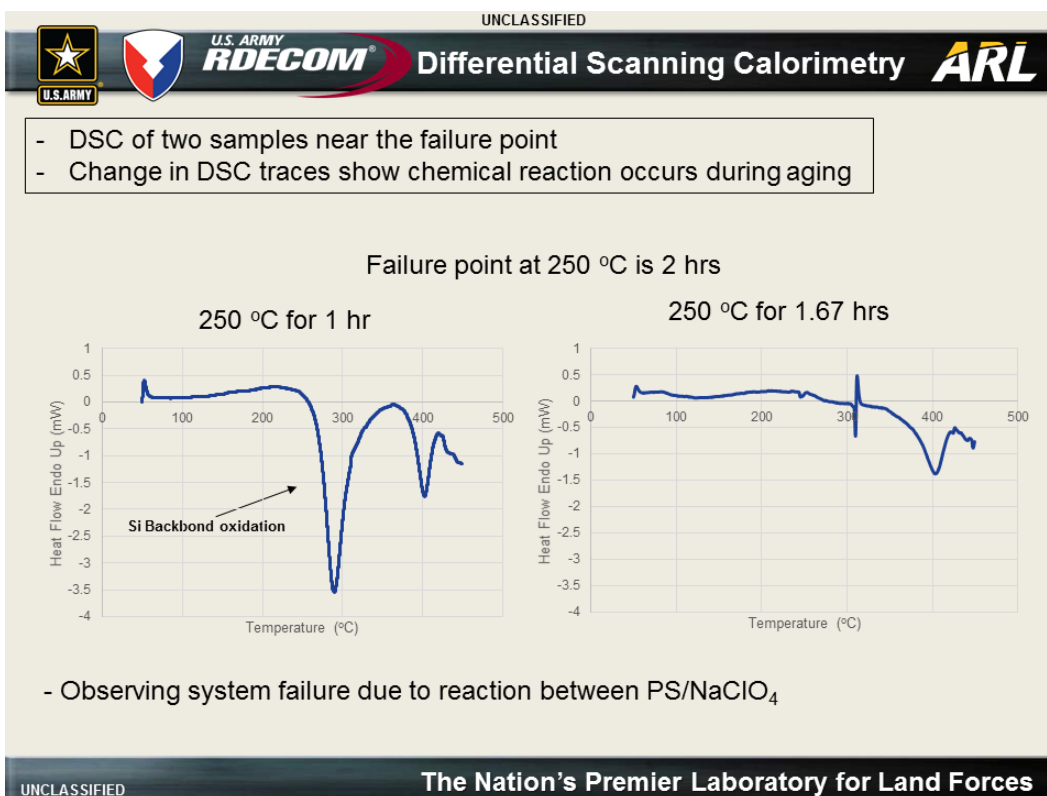
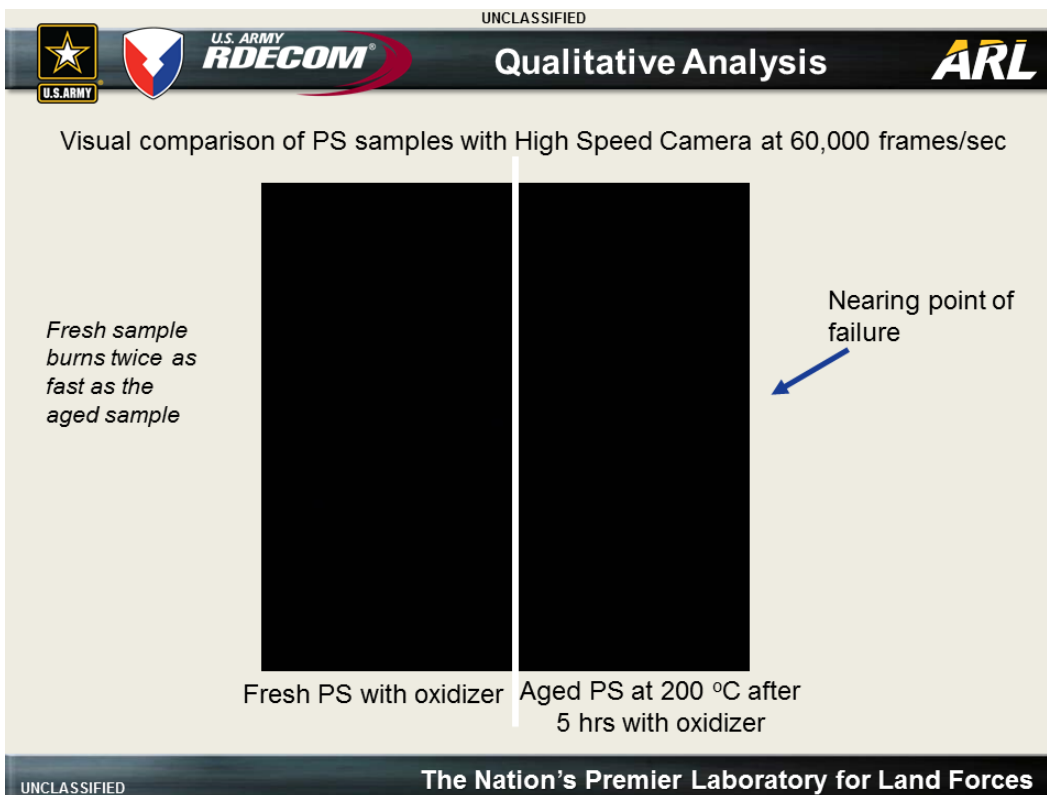


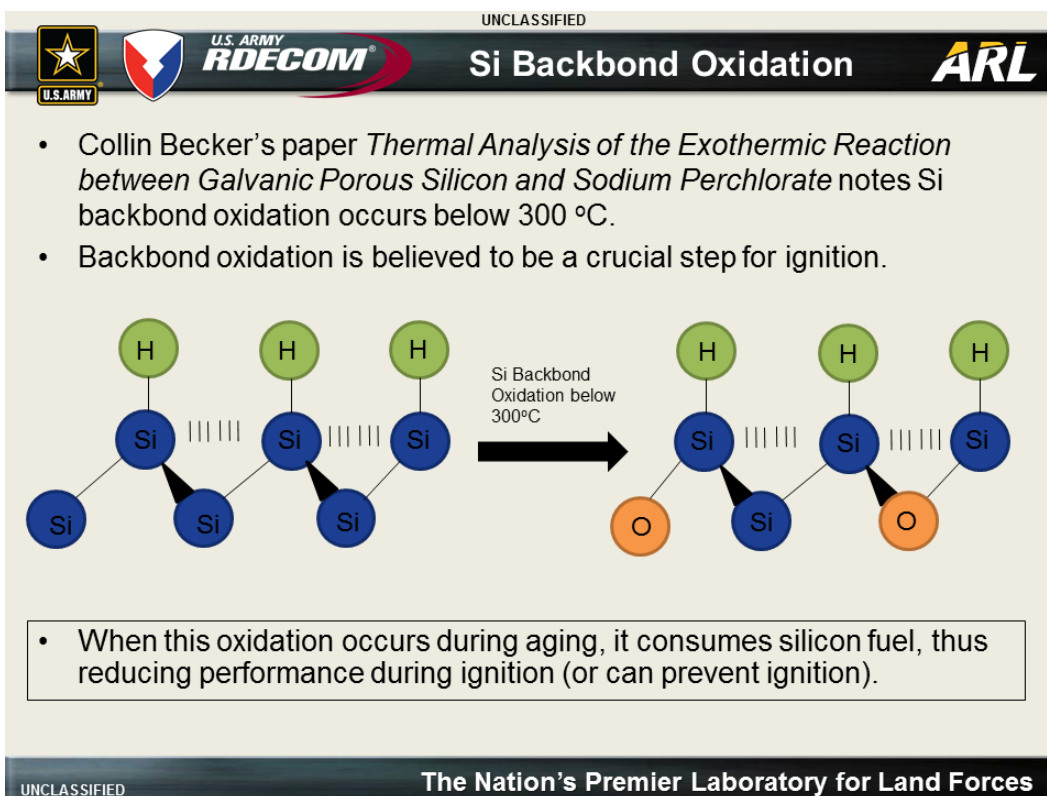
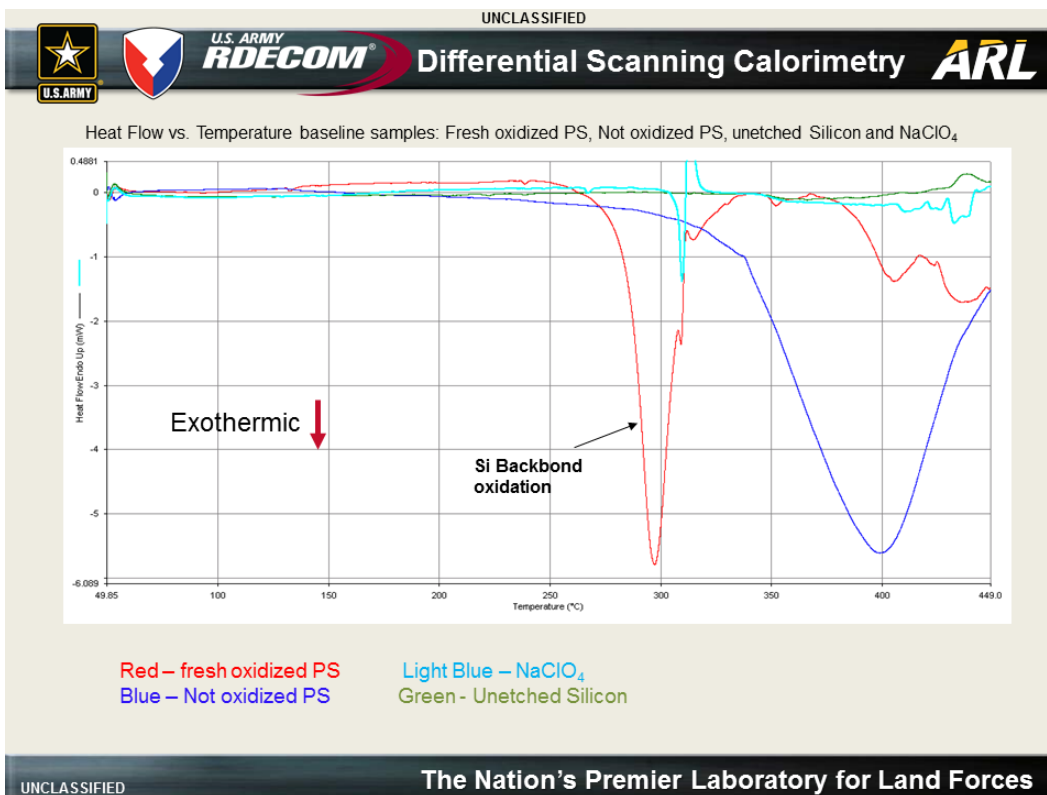
Fresh PS with oxidizer



Aged PS at 200°C after 5 hrs with oxidizer







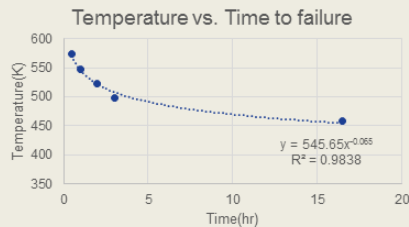


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## Conclusions



- Investigated lifetime of PS through accelerated aging tests in support of mission critical Army programs
- Obtained an estimated lifetime of PS at ambient conditions ~ 23 years
- Demonstrated aging affects chemical nature of PS
  - Electrical data showed no effect on electrical connections
  - DSC showed evidence of impacting Si backbond oxidation
- **Study shows importance of Si backbond oxidation in ignition and knowledge can be used in processing and storing PS+oxidizer systems**
  - When integrating with other MEMS devices or fabrication techniques, we now have temperatures guidelines for processing



- Future studies:
  - Obtain more failure times at varying temperatures
  - Humidity chamber experiments on packaged devices



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## Electrical and Optical Characterization of CVT Grown $\text{Mo}_x\text{W}_{1-x}\text{Te}_2$ Alloys

**Daniel Rhodes**

<sup>1</sup>Florida State University/NHMFL

Daniel Chenet<sup>2</sup>, Tyler Klarr<sup>3,4</sup>, Alexander Duerloo<sup>5</sup>, Alex  
Mazzoni<sup>3,6</sup>, Sina Najmaei<sup>3</sup>, Qiu Run Zhang<sup>1</sup>, Robert Burke<sup>3</sup>

**Mentor:** Matthew Chin<sup>3</sup>

**Team Leader:** Madan Dubey<sup>3</sup>

**PHD Advisor:** Dr. Luis Balicas<sup>1</sup>

<sup>2</sup>Columbia University, <sup>3</sup>ARL, <sup>4</sup>Oregon State University, <sup>5</sup>Stanford University, <sup>6</sup>University of Maryland

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## Properties of 2D Materials **ARL**

### Graphene



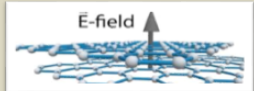
### Bandgap

$$E_g = 0 \text{ eV}$$

### Properties

- Ambipolar conduction
- Best thermal conductivity (in-plane)
- Record  $e^-/h^+$  mobility

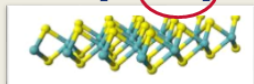
### Bilayer Graphene



$$E_g = f(E)$$

- Direct bandgap controlled by E-field
- Potential for exciton condensate

### $\text{MoS}_2$ or $\text{MoTe}_2$

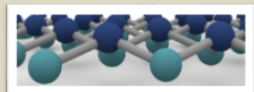


$$E_{g-\text{mono}}(\text{MoS}_2) = 1.8 \text{ eV direct}$$

$$E_{g-\text{mono}}(\text{MoTe}_2) = 1.1 \text{ eV direct}$$

- Excellent semiconductor
- Phase transition (1T Metallic to 2H Semico.)
- Can be used in optoelectronics

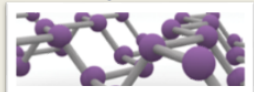
### Silicene



$$E_g = 0.1-0.5 \text{ eV indirect}$$

- Bandgap is tunable based on doping
- Semiconductor industry compatible
- Stability issues

### Phosphorene



$$E_g = 0.3-1 \text{ eV direct}$$

- Bandgap is tunable based on thickness
- Mobility predicted to be  $10,000 \text{ cm}^2/\text{V}\cdot\text{s}$
- Stability issues

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### Project Goals:

- Modulate the bandgap of  $\text{MoTe}_2$  by alloying with  $\text{WTe}_2$ .
- Adjust stoichiometry to tune metal-to-semiconductor phase transition temperature.
- Develop unique device fabrication techniques.

### Background Motivation and Relevance for ARL/Army:

- Could offer a route to sensitive 2D infrared detectors.
- Possible applications in 2D thermally sensitive devices.
- Non-volatile memory.
- Strain modulated transistors.

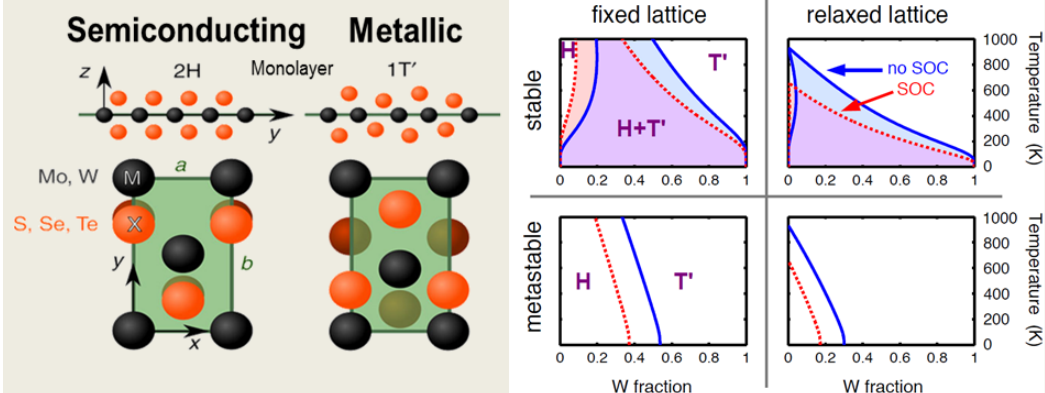
### Technical Challenges:

- Producing selective stoichiometry.
- Analyzing and understanding the photon-phonon interactions via Raman.
- Observing the bandgap and gradual transition into metallic phase.
- Creating electrical devices to apply thermal energy or strain.

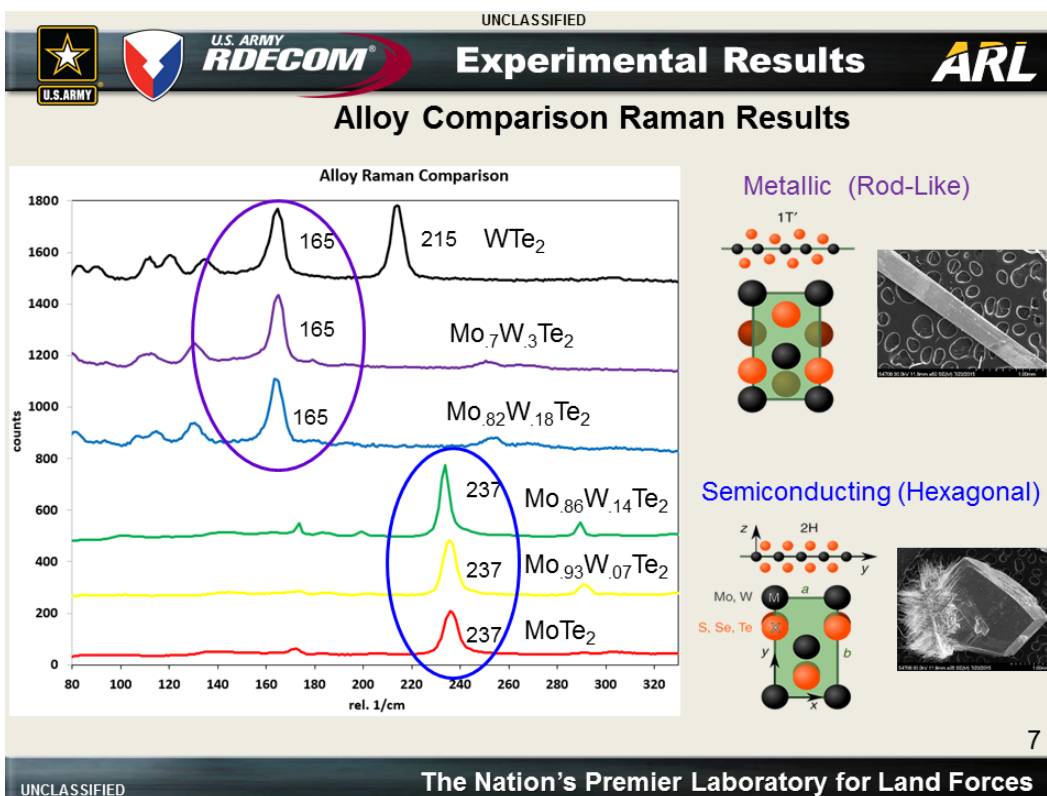
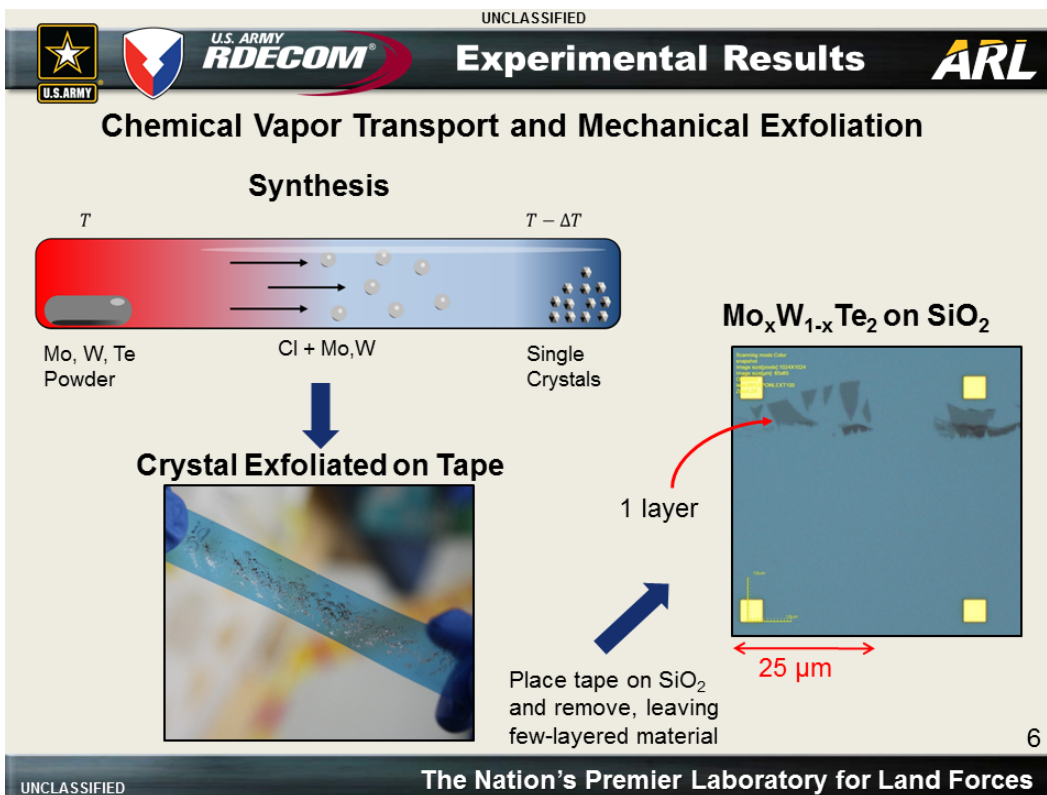
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### Theoretical Phase Diagram

- ..... Spin Orbit Coupling
- No Spin Orbit Coupling



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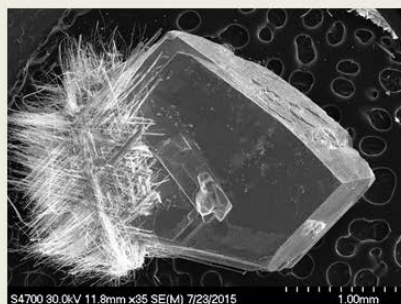




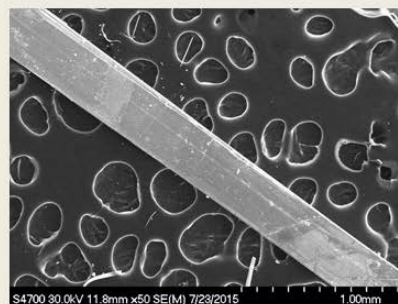
## EDX Results

Phase	Mo Atomic %	W Atomic %	Te Atomic %	W:Mo Ratio	Overall Stoichiometry
1T'	23.5	11.0	65.4	.47	$\text{Mo}_{.68}\text{W}_{.32}\text{Te}_{1.9}$
1T'	23.6	9.6	66.8	.41	$\text{Mo}_{.71}\text{W}_{.29}\text{Te}_2$
2H	28.7	4.6	66.8	.16	$\text{Mo}_{.86}\text{W}_{.14}\text{Te}_2$
2H	29.8	2.8	67.5	.09	$\text{Mo}_{.92}\text{W}_{.08}\text{Te}_{2.1}$

2H crystal with 1T growing from the edge



Single 1T bulk crystal

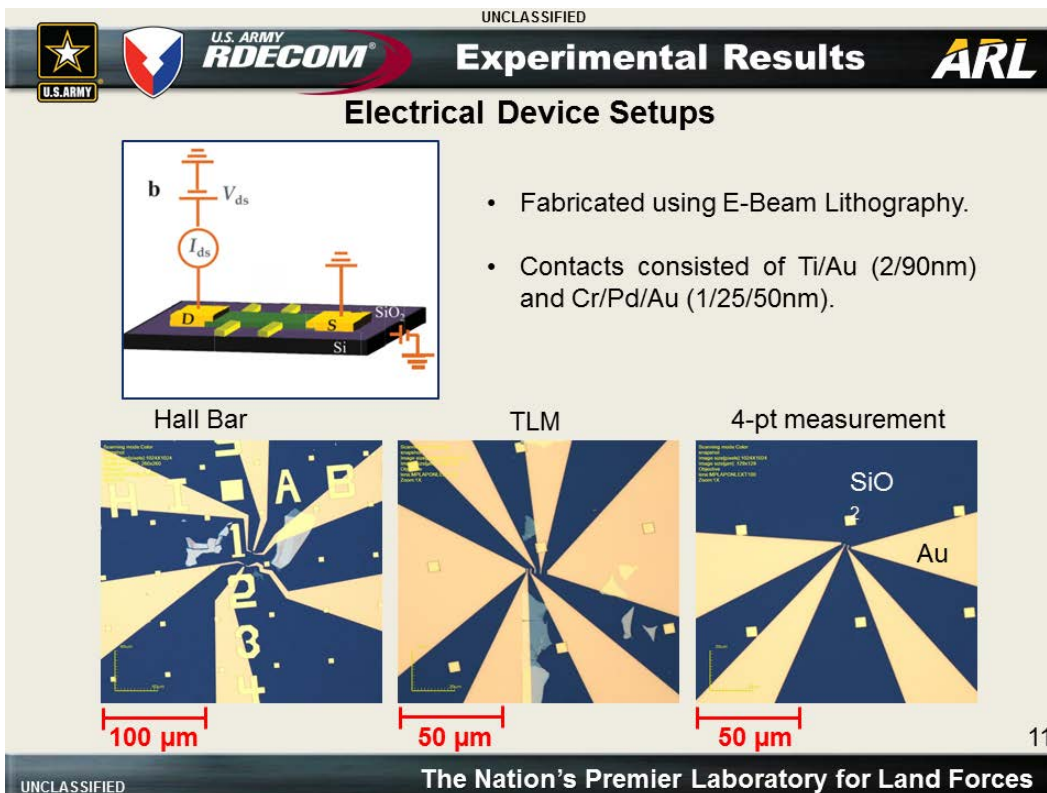
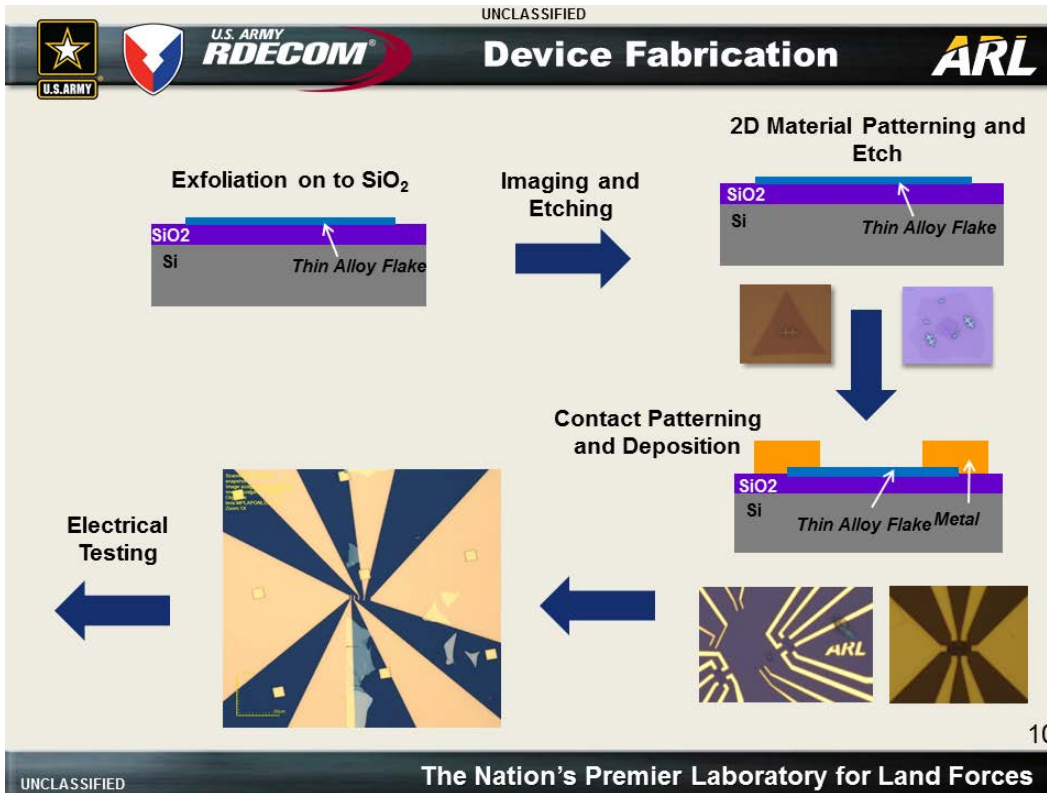


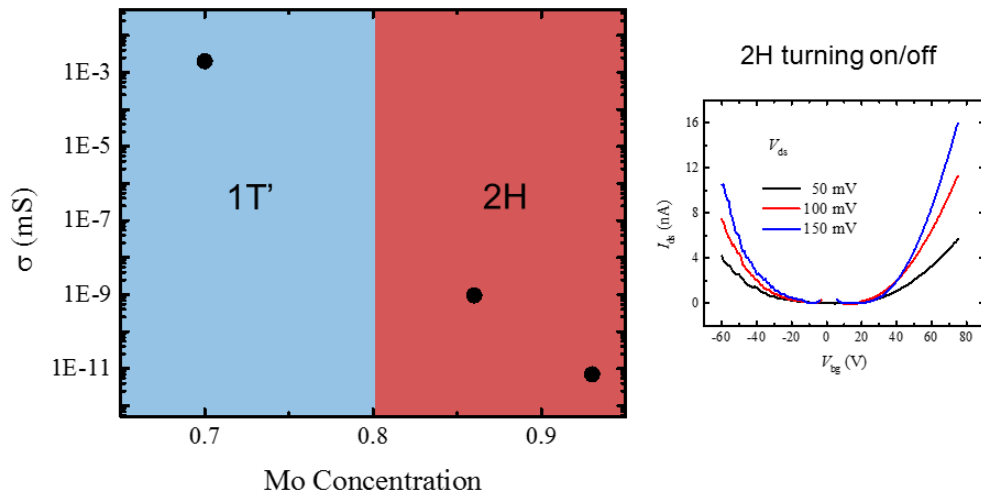
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## Phase transition via laser exposure



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  **U.S. ARMY RDECOM** **Future Work** 

- Temperature dependence of current 2D materials using a graphene heater.
- More materials characterization (TEM, TOF-SIMS, XPS, XRD, and EDX).
- Further synthesis and tuning of the phase transition from growth.
- Temperature and polarization-dependent Raman analysis.
- Contact optimization for more reliable electrical measurements and more electrical measurements.
- Refining laser patterning of 1T' phase.
- Strain-device engineering or thermal device engineering to induce phase transition from 2H to 1T'.

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  **U.S. ARMY RDECOM** **Acknowledgments** 

I would like to thank ARL for the opportunity to conduct interesting and meaningful research as an intern.

I would also like to acknowledge ARO and the NSF for facilities and support before arriving at ARL.

Thanks to those who helped me with this project:

Daniel Chenet*	Sina Najmaei
Tyler Klarr*	Madan Dubey (Team Leader)
Alex Mazzoni	Luis Balicas (PHD Advisor)
Matthew Chin (Mentor)	
Matthew Hwee	
Robert Burke	

(\*contributed towards Raman, composition characterization, and planning project)

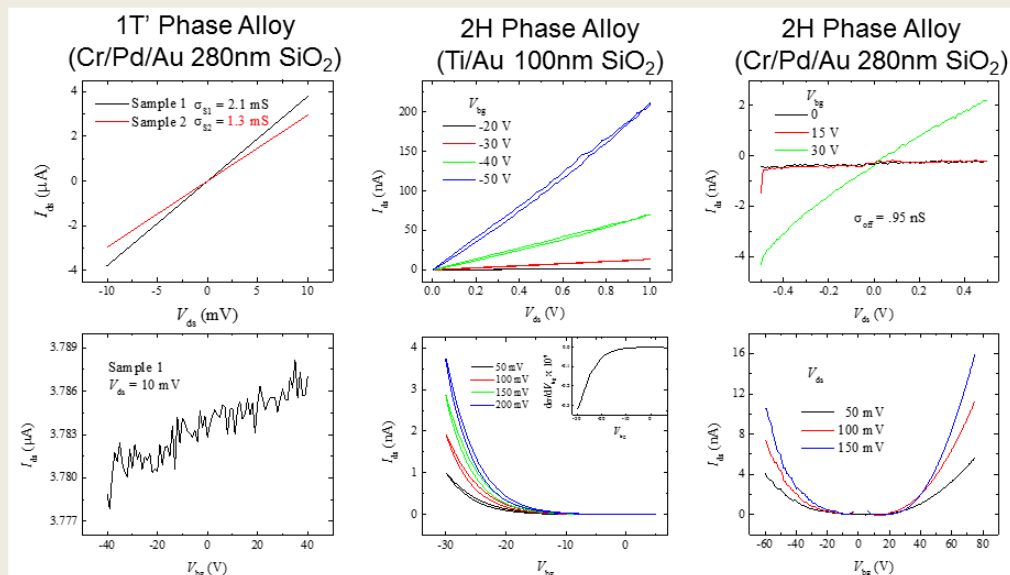
And a particular thanks to Alexander Duerloo and Evan Reed for providing theoretical calculations.

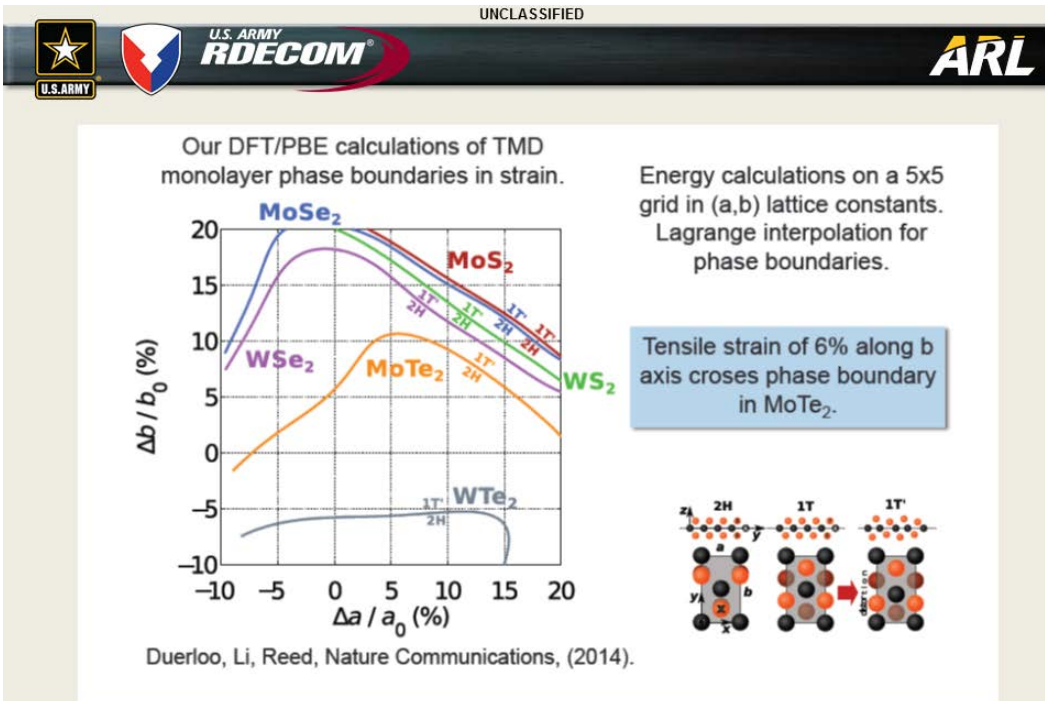
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Thank you for your time.

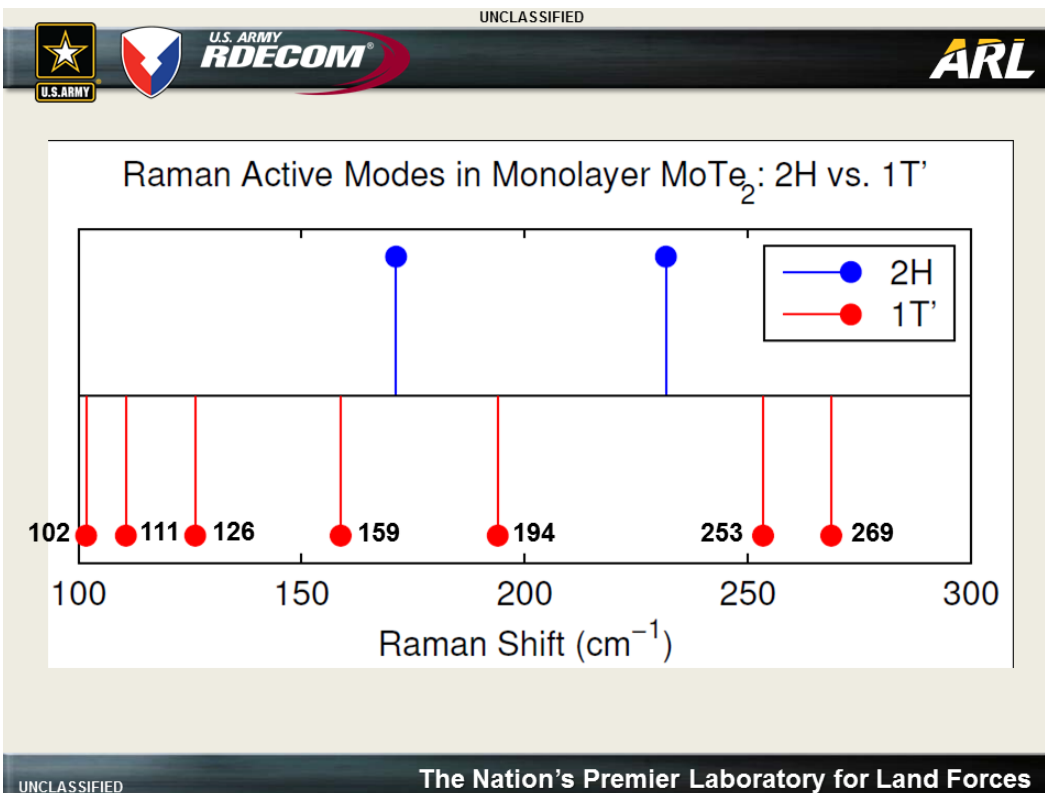
### Electrical Conductivity for 2H and 1T



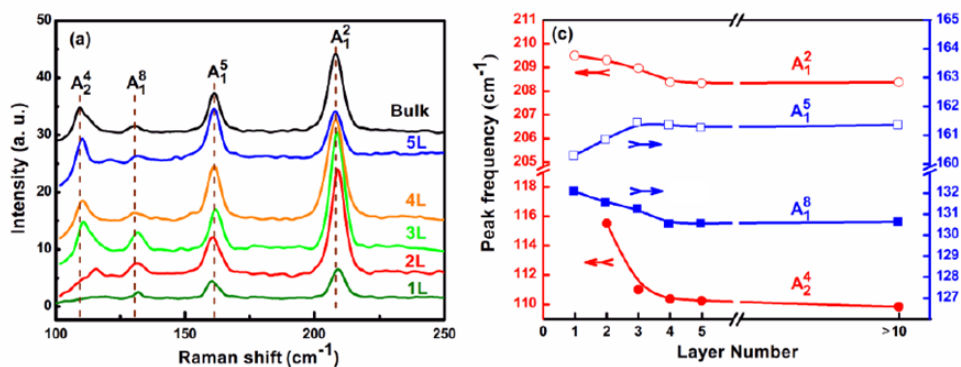


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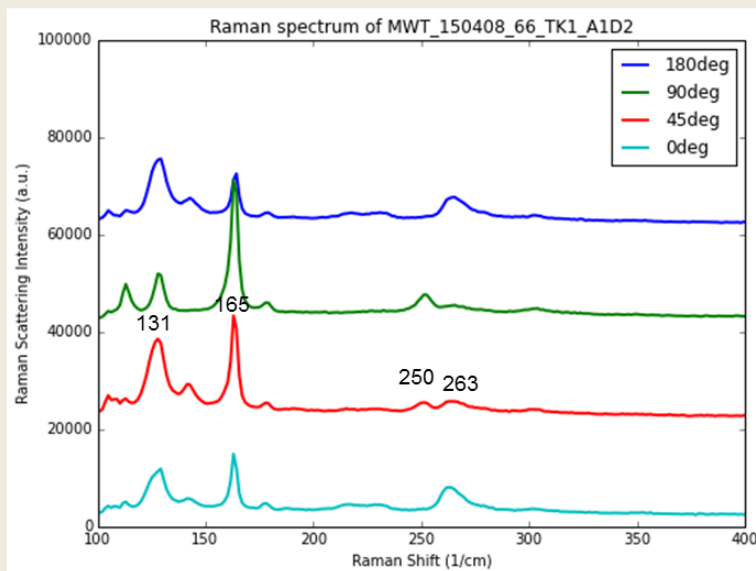
## WTe<sub>2</sub> Raman Peaks and Layer Dependence

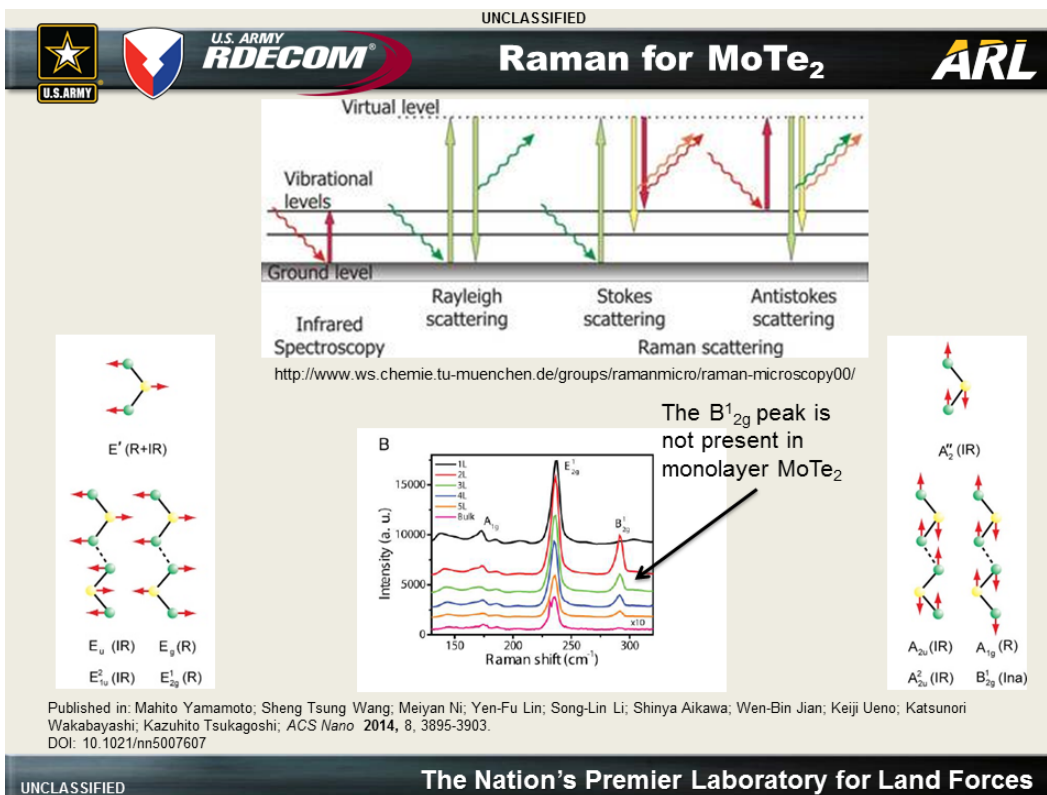


Yucheng Jiang, Ju Gao, arXiv:1501.04898 (2015)

## Experimental Results

### Polarization Dependent Raman Results





## **Vehicle Technology Directorate (VTD)**

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## Active Flap Rotor Modeling for Aeromechanics Predictions

**Ethan Corle**

Department of Aerospace Engineering  
The Pennsylvania State University

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Outline

**ARL**

- **Motivation**
- **Background**
- **Methodology**
  - **RCAS Model**
- **Results**
  - **Fan Plots**
  - **Load Comparisons**

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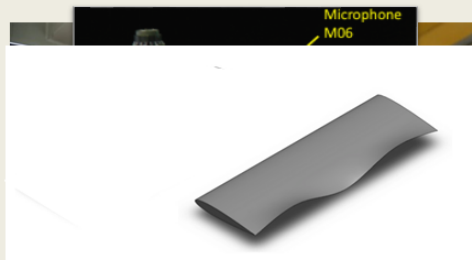
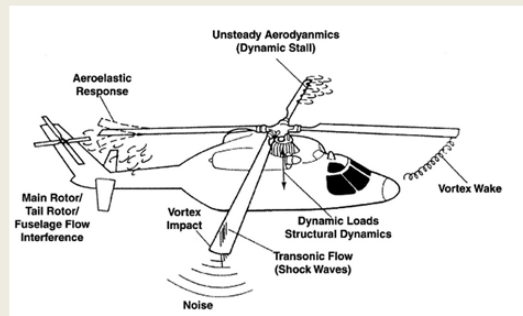
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**RDECOM****Motivation****ARL****Compromised design of rotor blades**

- Differing aerodynamic conditions across flight envelope.

**Active rotor technologies**

- Dynamically change airfoil characteristics to alter blade loading
  - Both aerodynamic and structural effects
  - Used to increase performance, reduce vibrations, and reduce noise



Blade Morphing (University of Virginia)

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**RDECOM****SMART Rotor****ARL****Smart Material Advance Rotor Technologies (SMART) Rotor Program**

- DARPA Helicopter Quietening Program
- Army, NASA, Boeing
- Designed to improve and validate the current state-of-the-art in active rotor modeling
- Accurate models can provide reliable predictions prior to expensive testing

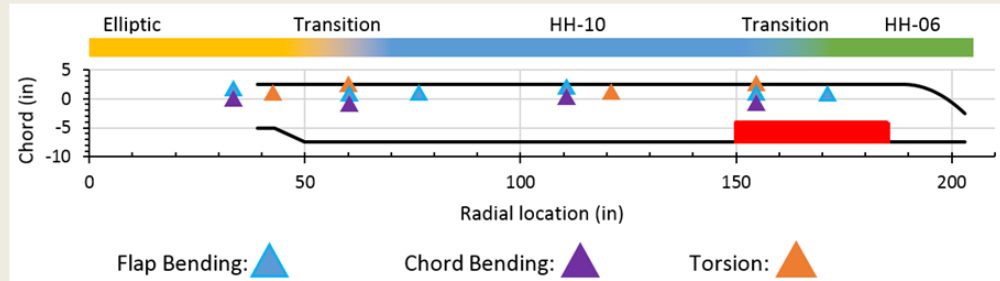
**End Goal:** Investigate active flap aeromechanics and utilize understanding to make optimized flap deployment schedules



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### SMART Rotor Test Campaign



### Planned Deployments

**Table 1. Planned SMART Rotor Test Cases**

Name	$C_T/\sigma$	$\mu$	Deployment Schedule
MDART	0.080	0.3	$\delta_n = 0^\circ$
SMART1	0.080	0.3	$\delta_n = 2^\circ \cdot \sin(5 \cdot \psi_n + 90^\circ)$
SMART2	0.080	0.3	$\delta_n = 2^\circ \cdot \sin(3 \cdot \psi_n + 60^\circ)$
SMART3	0.070	0.375	$\delta_n = 1^\circ \cdot \sin(5 \cdot \psi_n + 180^\circ)$
SMART4	0.075	0.3	$\delta_n = 2^\circ \cdot \sin(2 \cdot \psi_n + 240^\circ) + 1^\circ \cdot \sin(5 \cdot \psi_n + 330^\circ)$

Where  $n$  is the blade index

(Straub et al. – 2009, Lau et al. – 2010)

### Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics (CAMRAD) II Modeling (Kottapalli – 2010, 2011)

- **Predictions:**
  - Flap hinge stiffness sensitivity
  - Alterations to airfoil tables

### Coupled fluid-structure modeling (Potsdam et al. – 2010)

- OVERFLOW 2.0aa and CAMRAD II
- Challenging multidisciplinary problem
- Little improvement over comprehensive analysis

### Current state of the art

- Large discrepancies between analysis and test data
- Aeromechanics of active flap not fully understood



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Computational Tools

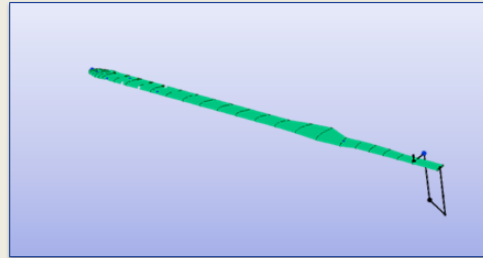
**ARL**

## The Rotorcraft Comprehensive Analysis System (RCAS)

- Army-owned multidisciplinary, flexible multibody for rotorcraft aeromechanic analysis

### RCAS Structural Model

- Geometrically exact
  - Control system
  - Blade root connections
  - Flap connections
- Nonlinear beam elements
  - Sectional material properties
  - Separate elements for blade and flap segments



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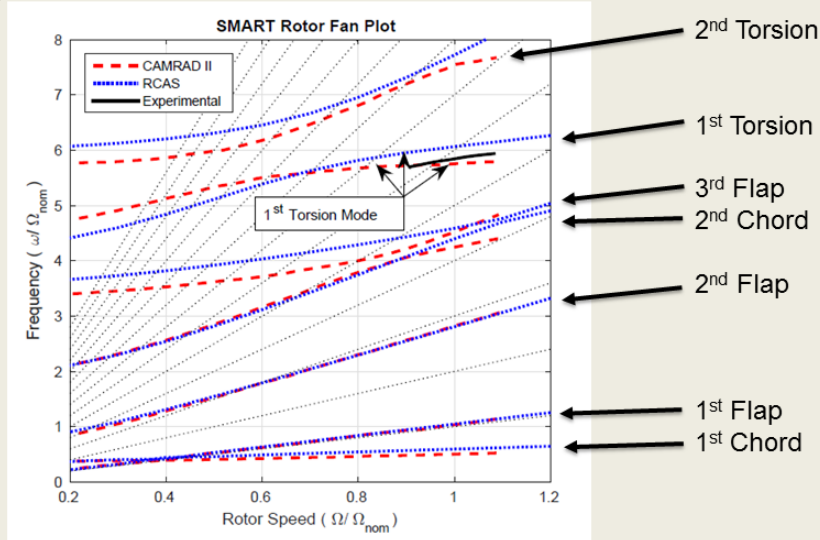


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Structural Natural Frequencies

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Structural model is in good agreement with previous studies

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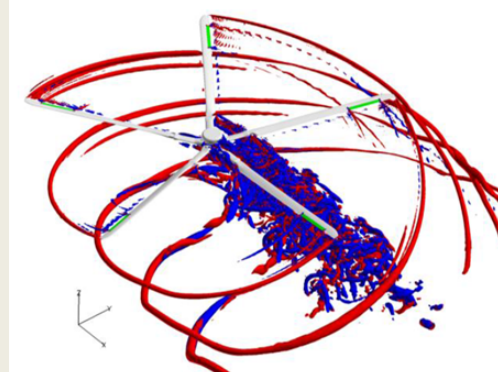
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Computational Tools

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### RCAS Aerodynamic Model

- Nonlinear, unsteady
- Computationally efficient
- Empirical model for blade/flap effects
- Trimmed to fixed  $C_T/\sigma$  and measure pitch and roll moments



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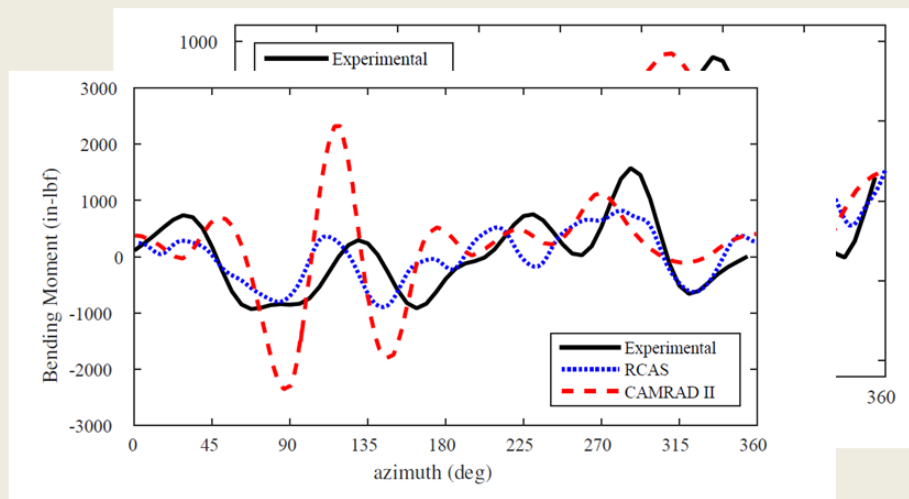
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Results

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### SMART1: Flap Bending Moment 89% Span

$$V = 208 \frac{ft}{s}, \quad \delta_{flap} = 2^\circ \sin(5\psi_n + 90^\circ)$$



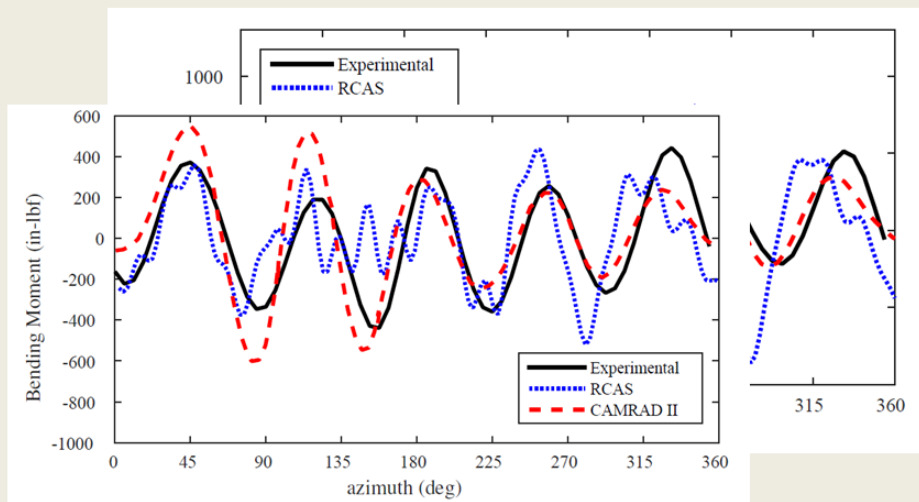
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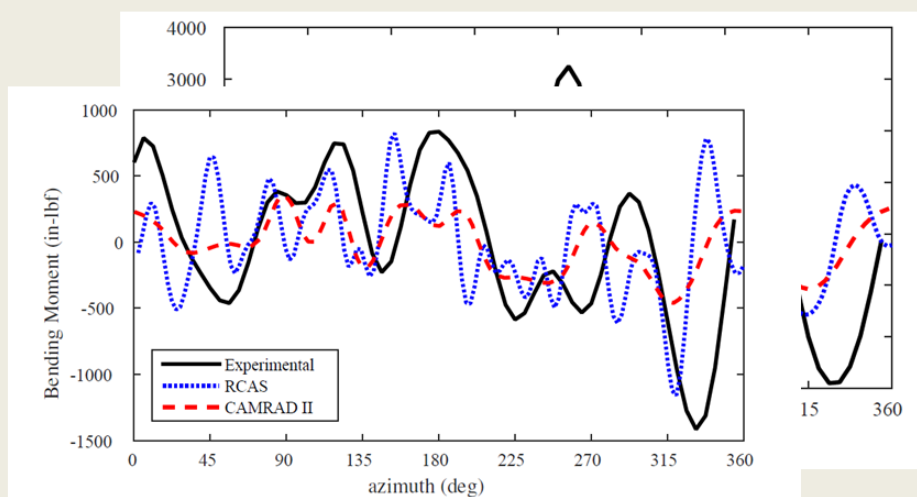
### SMART1: Torsion 64% Span

$$V = 208 \frac{ft}{s}, \quad \delta_{flap} = 2^\circ \sin(5\psi_n + 90^\circ)$$



### SMART1: Chord Bending Moment 89% Span

$$V = 208 \frac{ft}{s}, \quad \delta_{flap} = 2^\circ \sin(5\psi_n + 90^\circ)$$



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**RDECOM****Conclusion & Looking Forward****Conclusion**

- **First RCAS SMART rotor model developed and validated**
  - Good correlation with structural model
  - Fair correlation with experimental loading data
- **Higher harmonic content observed in chordwise bending and torsional loads**
  - Blade flap interference model not adequate to complex aerodynamic interactions

**What's Next?**

- **Finish baseline cases for other SMART deployments**
- **Investigate alternative flap modeling**
- **Implement Helios for CFD/CSD predictions**

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**RDECOM****Acknowledgements****Mentors:**

- **Rajneesh Singh**
- **Hao Kang**
- **Matthew Floros**
- **Sven Schmitz**



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## **Weapons & Materials Research Directorate (WMRD)**

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# Characterizing the Internal Morphology of KM2 Ballistic Fibers



Taylor Stockdale, Dr. Emil Sandoz-Rosado, Dr. Ken Strawhecker

Composite & Hybrid Materials Branch

WMRD

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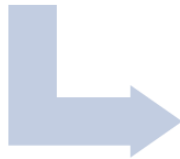


## My Background



### Undergraduate

- Simpson College
- Physics, Mathematics



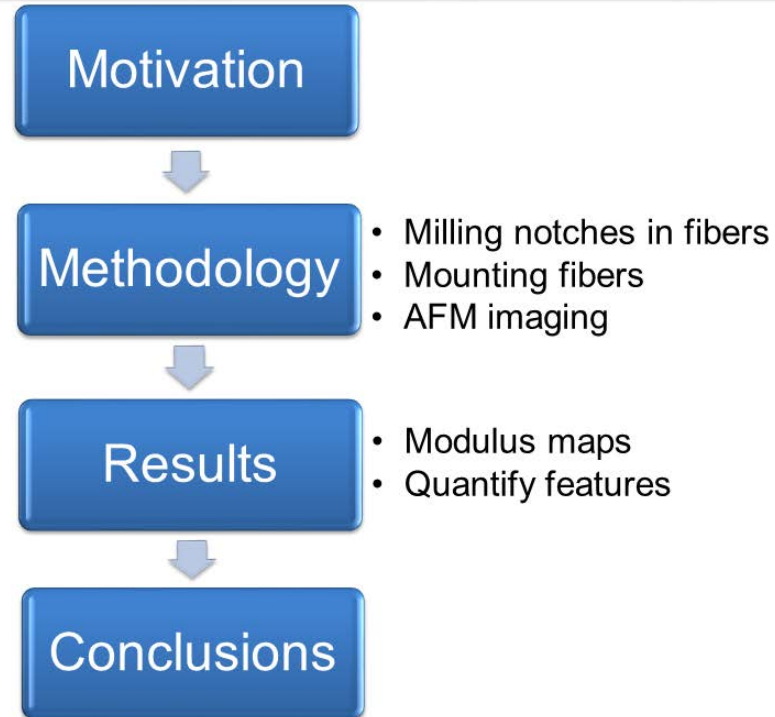
### Graduate

- University of Nebraska-Lincoln
- Second-year PhD student
- Materials Engineering

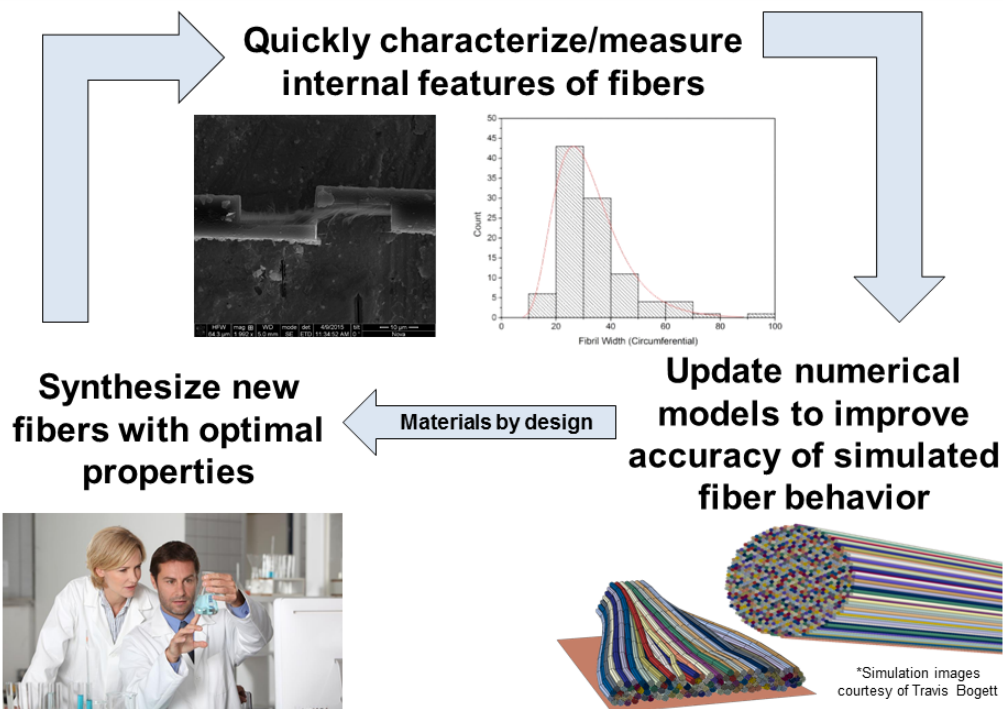
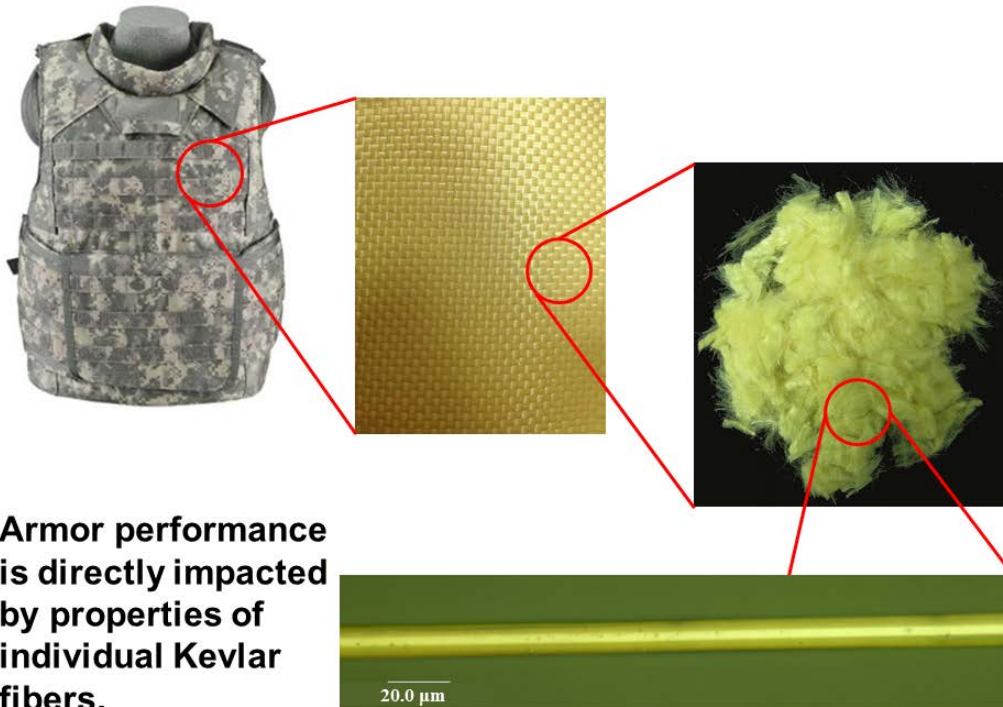


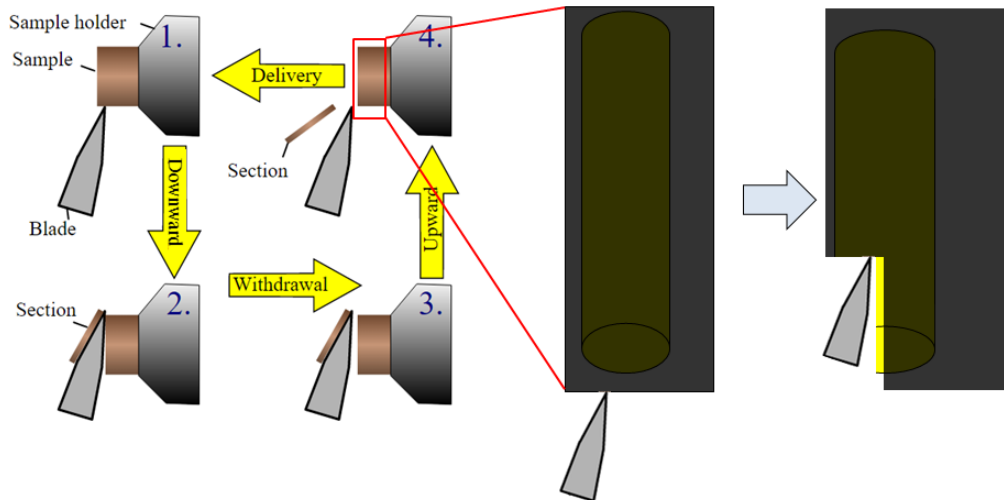
### ARL

- First summer
- New characterization techniques

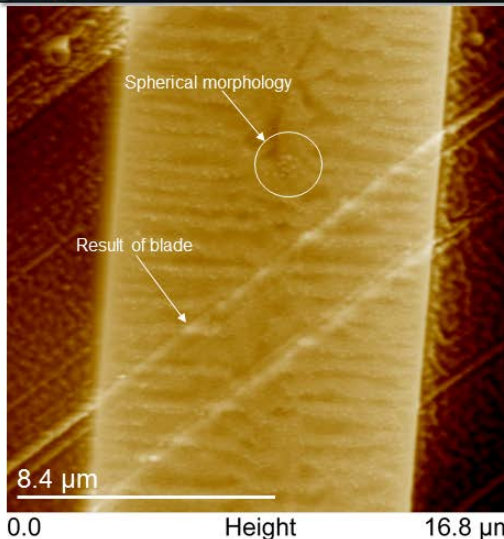


# Motivation



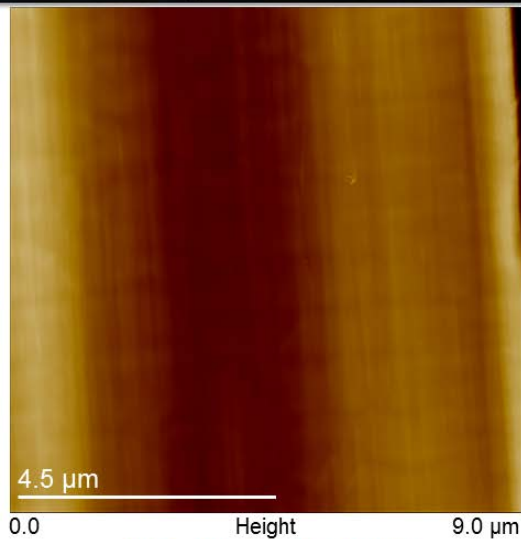


- Very little work done to characterize internal features of high performance fibers
- Previous studies utilize microtomy to observe internal features of Kevlar and UHMWPE
  - Dobb et al. Journal of Polymer Science (1977), McDaniel et al. Polymer (2015)



**KM2 – Microtome**

- Lengthy process ( $\geq 24$  hrs/sample)
- Sorting of features
- Odd spherical morphology develops over time

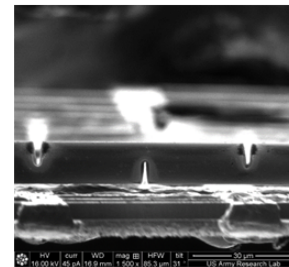
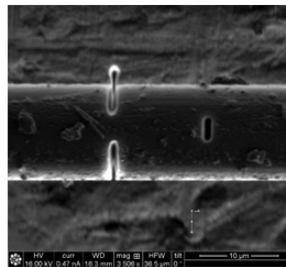
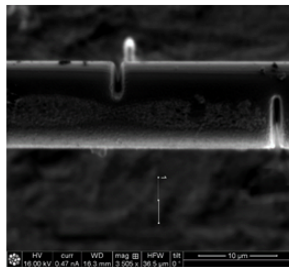


**KM2 – Our New Technique:  
Induce Longitudinal Shear**

- Time-efficient ( $< 2$  hrs/sample)
- No mechanical agitation of internal features
- No time-related effects



# Methodology

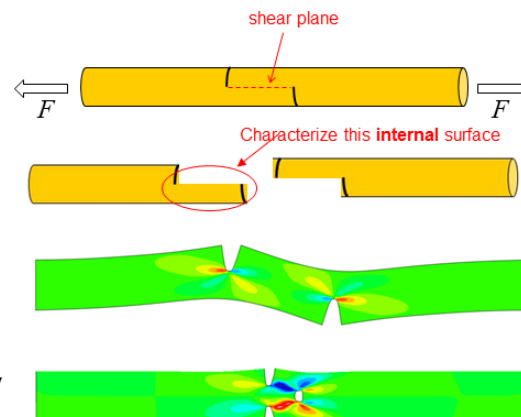


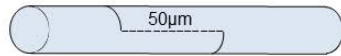
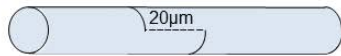
## Objective:

Develop test methods for characterizing ballistic fibers after inducing longitudinal shear.

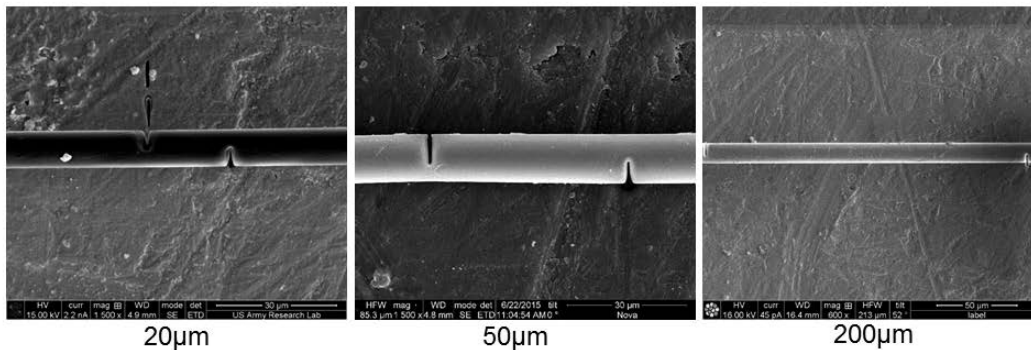
## Approach:

- Use focused ion beam (FIB) milling to create notches in single fibers to produce a shear plane.
- Characterize internal surface morphology by atomic force microscopy (AFM).

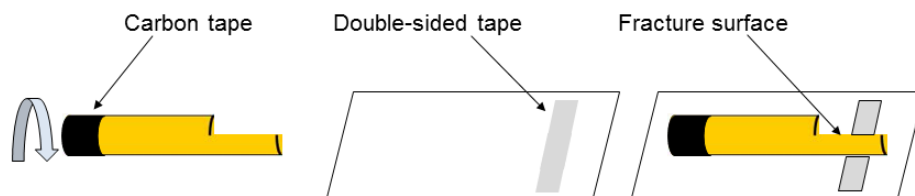




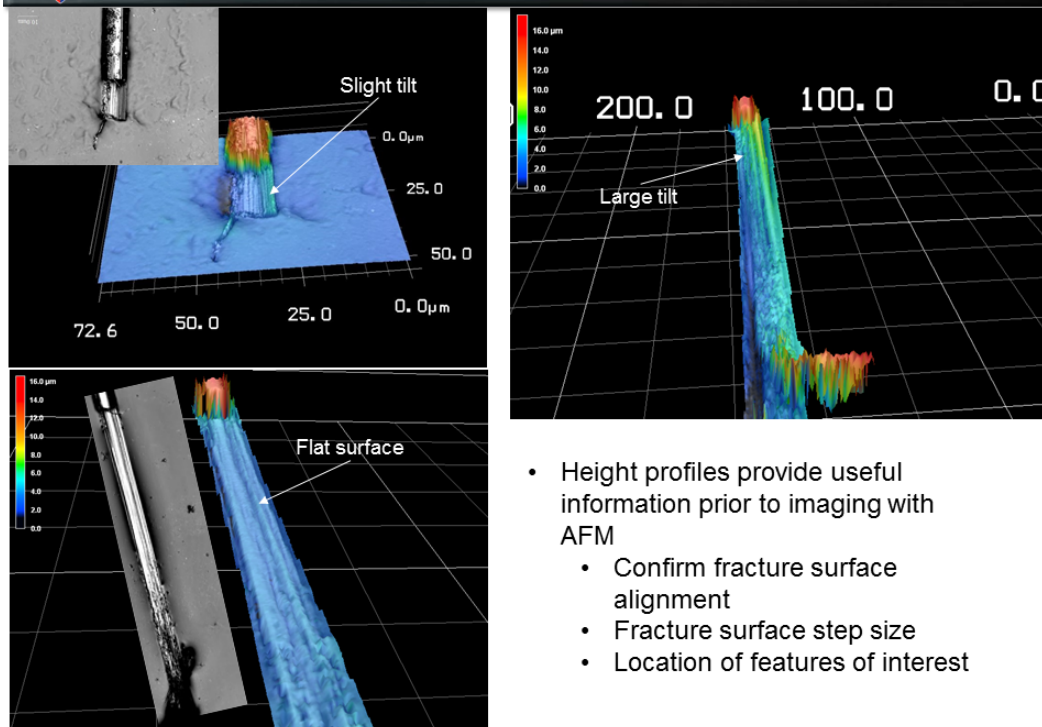
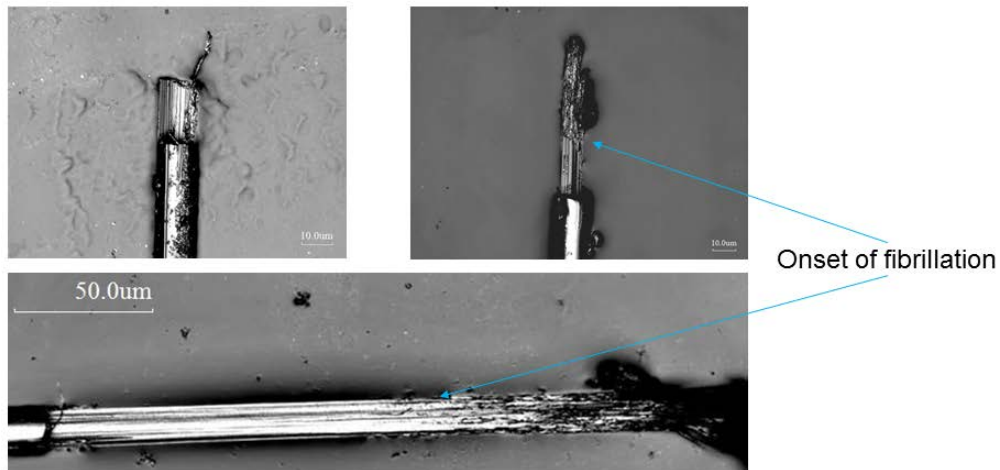
- Notches eliminate longitudinal strength of fibers making them extremely fragile
- Fibers fractured in tension
- After fibers are fractured they must be mounted in the correct alignment for imaging



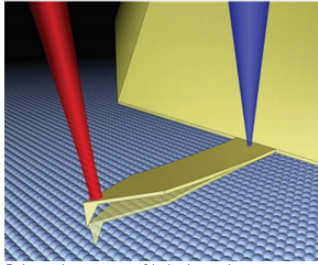
- Fix back end of fiber to carbon tape allowing rotational freedom.
- Use optical microscope as visual aid and rotate fiber until fracture surface is facing up.
- Fix tip of fiber to double-sided adhesive tape to secure fiber for imaging.



- Initial imaging performed using Keyence 3D laser scanning confocal microscope.
- Height profiles are generated to confirm fracture surface alignment is maintained after mounting.



- Height profiles provide useful information prior to imaging with AFM
  - Confirm fracture surface alignment
  - Fracture surface step size
  - Location of features of interest

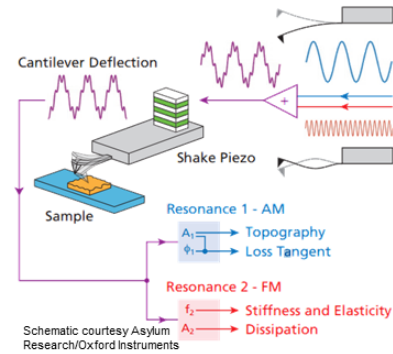


Schematic courtesy of Labuda et al.

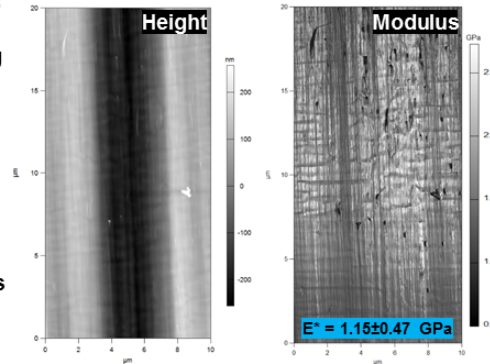
Taylor expansion SHO  
+ Hertz model

$$k_{ts} = 2aE^*$$

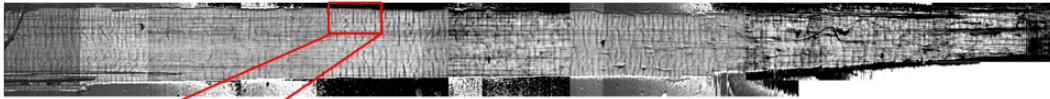
$$E^* = \frac{\Delta f_2 k_2}{f_{0.2} a}$$



- Cypher's unique feature (blueDrive) directly drives cantilever with blue laser
  - Provides simple and extremely precise tuning of cantilever
- Operate in AMFM mode (Tapping mode)
- Generate modulus maps
  - Hertz model for contact mechanics
  - Changes in second resonant frequency correspond to differences in material stiffness

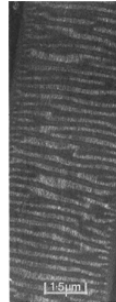
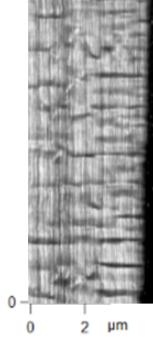


## Results

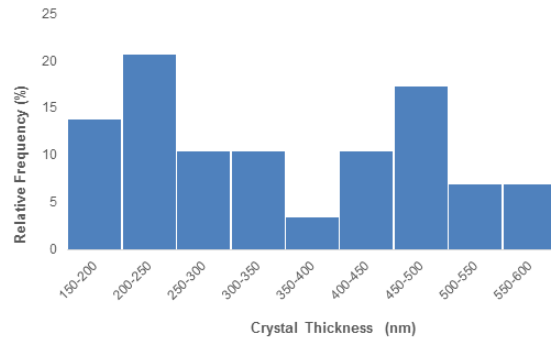
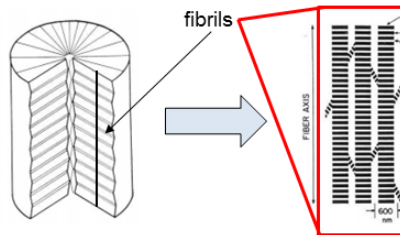


AFM

DFTEM

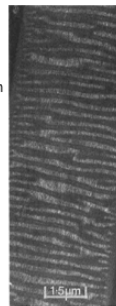
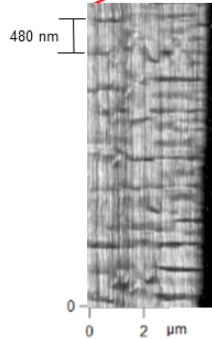


- Transverse banding appears periodic resembling pleated sheet structure
  - Dobb et al., Journal of Polymer Science (1977)
- Spacing between bands indicates characteristic length of crystallites
  - Panar et al., Journal of Polymer Science (1983)
- Bimodal distribution → core-shell

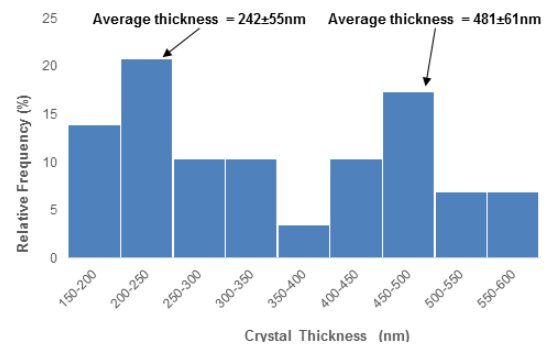
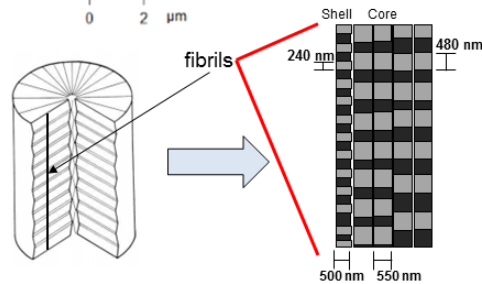


AFM

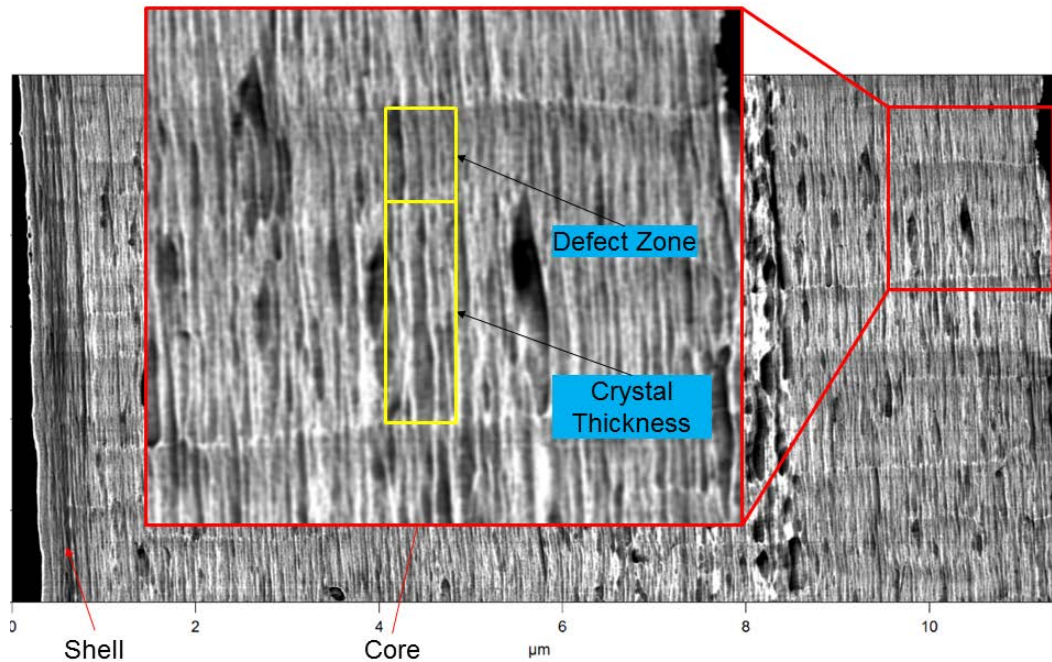
DFTEM



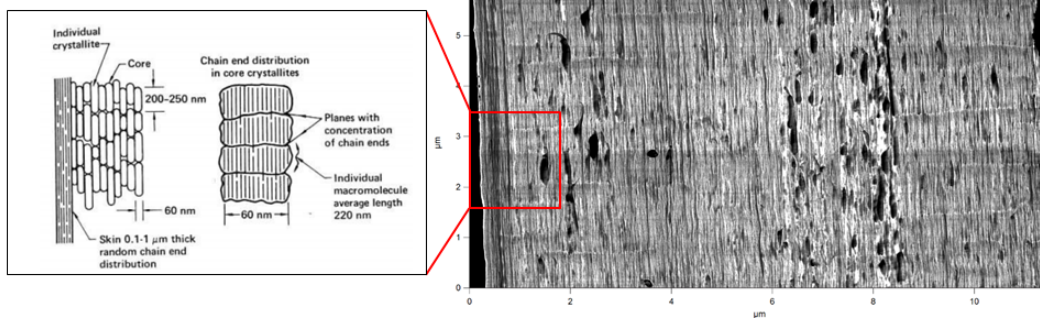
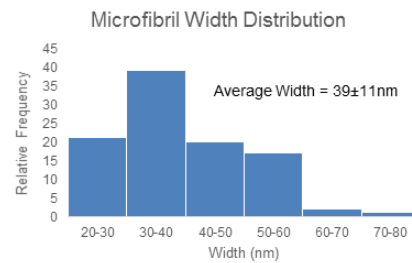
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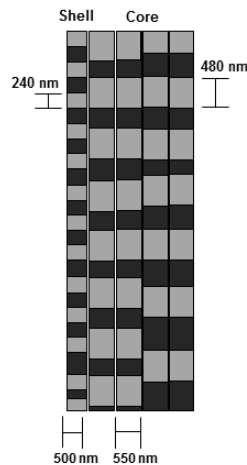
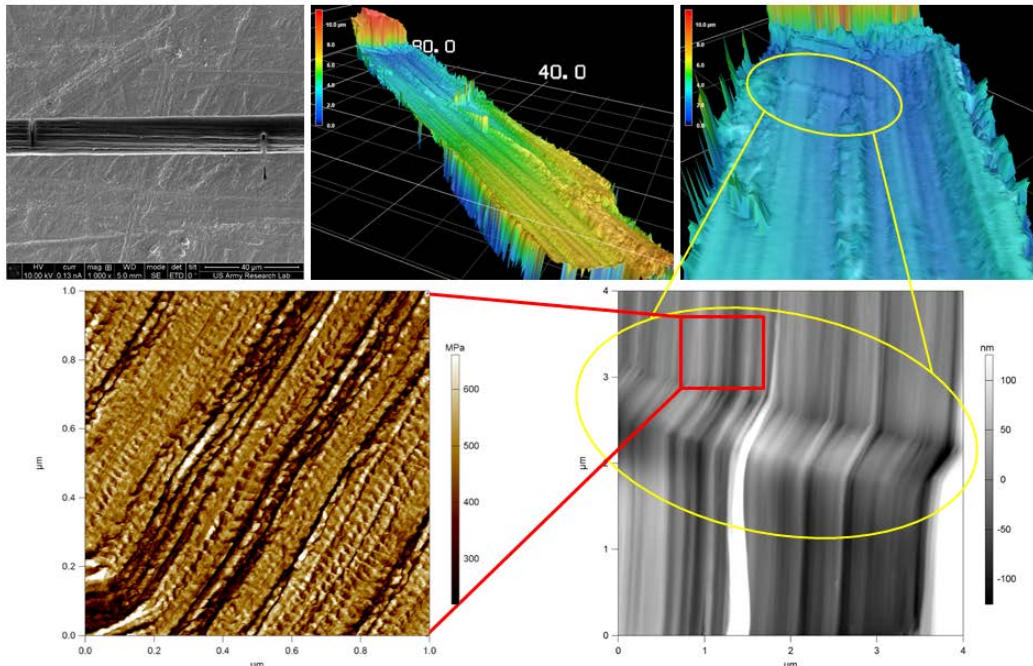


- High resolution scan shows microfibrillar structure, which resembles chain-end model of poly(*p*-phenylene terephthalamide) (PPTA) fibers.
  - Morgan et al., Journal of Polymer Science (1983)
- Modulus of core = 1.15 GPa
- Modulus of shell = 0.84 GPa (~**25% reduction**)

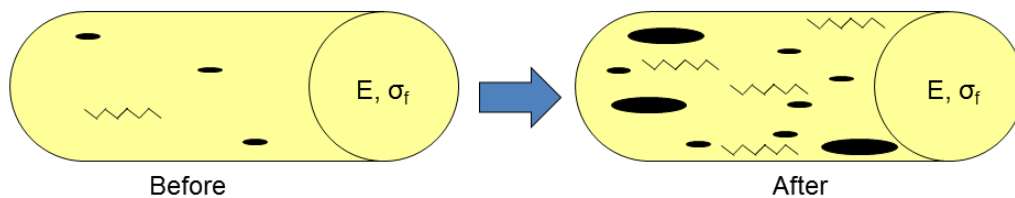


- Technique works for KM2 – what about other fiber systems?

- Technique applied to observe internal morphology of UHMWPE fibers – Dyneema SK76



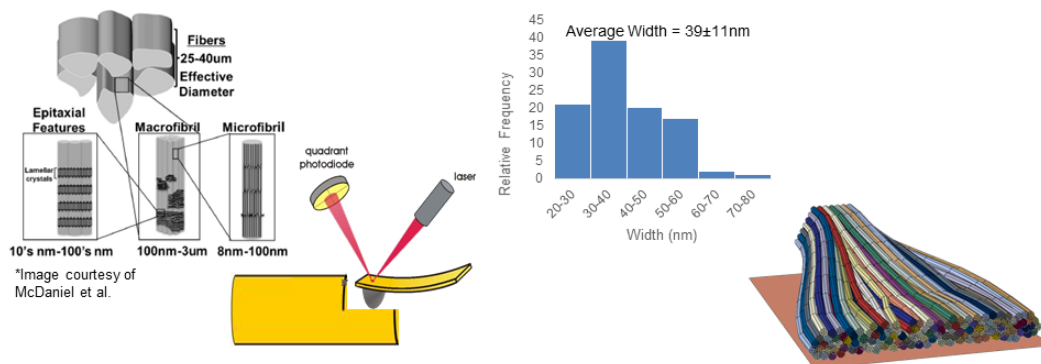
- Mechanical properties known for single KM2 fibers
- Next Step:** Correlate changes in internal morphology to changes in mechanical properties





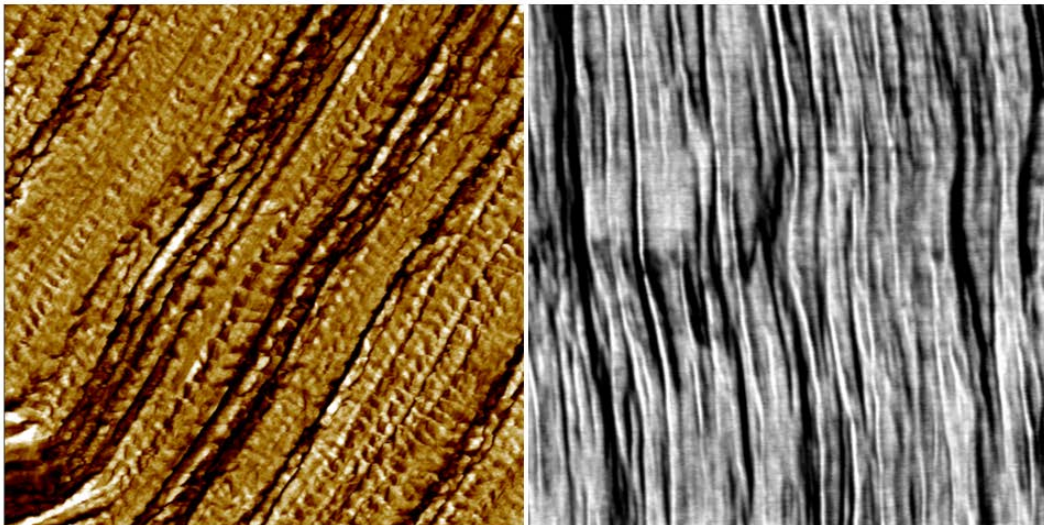
# Conclusions

- Successfully induced longitudinal shear in single Kevlar KM2 and UHMWPE fibers using FIB notch technique.
- Internal features of KM2 resemble those observed in Kevlar 49 via DFTEM.
- Our new technique is more time-efficient and less disruptive than microtomy.
- Technique can quantitatively show how changes in internal morphologies effect overall mechanical properties.



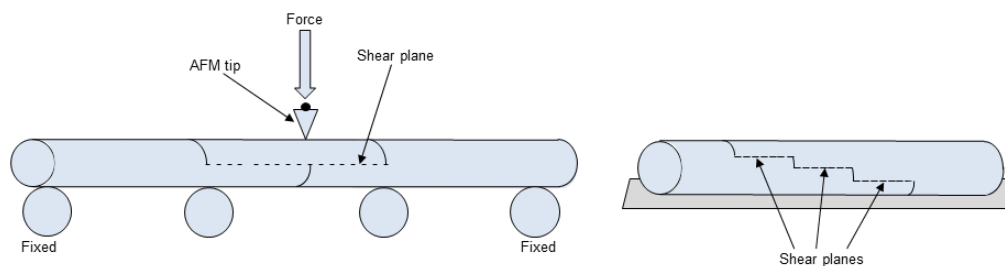
- Eric Wetzel
- Emil Sandoz-Rosado
- Ken Strawhecker
- Paul Moy
- Josh Taggart
- Jon Ligda
- Randy Mrozek
- ASEE
- CQL

## Questions?



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- **TEM Grid 3-point bending**
  - Short beam shear test uses 3 point bend test with span to thickness ratio of about 4:1 for inducing pure shear
  - 400 mesh TEM grid provides span:tk of about 5:1
- **Stepwise shear surfaces**
  - Provide through thickness observation of internal morphologies



ADMNSTR  
DEFNS TECHL INFO CTR  
ATTN DTIC OCP

US ARMY RSRCH LAB  
ATTN RDRL CIO LL TECHL LIB  
ATTN IMAL HRA MAIL & RECORDS MGMT  
ATTN RDRL DP ISABEL LLERENA  
ATTN RDRL WML B ROSE PESCE-RODRIGUEZ

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