



ARL-TM-2016 • JUN 2017



Volume I: Select Presentations

by ARL Summer Student Research Symposium

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REPORT DOCUMENTATION PAGE

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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 11 August 2016.</p> <p>Students selected by their directorate for competition participated in the one-day Summer Student Symposium on 11 August 2016. 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

The US 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 2016, 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.

Philip Perconti
Director

Introduction

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.

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 expected to write a paper on their work which summarizes their major activity and its end product.

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Students selected by their directorate for competition participated in the one-day Summer Student Symposium on 11 August 2016. 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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Human Research & Engineering Directorate (HRED)

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Applying Noise Stimulation to Improve Trigger Pull Steadiness

Christopher J. Blount, B.S.
The University of Texas at San Antonio

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Introduction

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What is Noise Stimulation?

- Application of Gaussian noise in the form of vibration to elicit an improved performance response
- Imperceptible (Not felt by participants)

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How can noise benefit steadiness?

Previous Studies

- Past studies have shown that introducing imperceptible noise stimulation to biological systems can increase force steadiness. (Mendez-Balbuena, 2012)
- The input of imperceptible noise could decrease motor unit force fluctuations. (Kouzaki, 2012)

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The Big Question:

How can I determine an optimal imperceptible noise level to increase force steadiness?

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Specific Aim 1

- To define the individual optimal imperceptible noise stimulation parameters that provide the greatest improvement in force steadiness in the muscles that produce the trigger pulling action.

Specific Aim 2

- To compare vibration stimulus placements at the forearm and wrist locations.

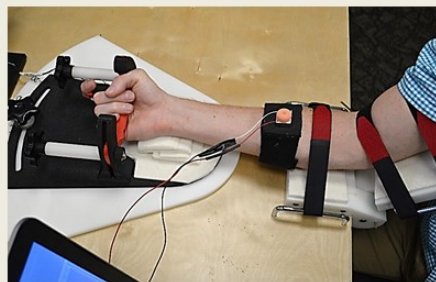
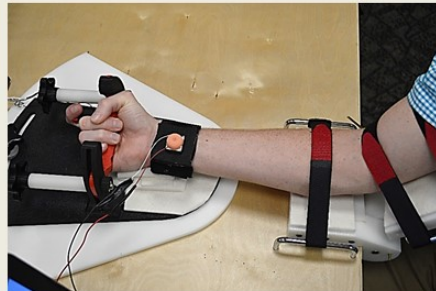
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Methods

7 male and 1 female participants completed the pilot study (n=8)

- Participants were seated with their dominant arm outstretched on a custom-made apparatus used to simulate the grip and trigger of an M4 carbine.
- Based upon verbal feedback, I determined the imperceptible vibratory threshold per individual.
- Vibration levels were applied to the participants skin at the wrist and forearm.
- Participants performed three maximal voluntary muscle contractions (MVCs).
- 20% of the greatest MVC was chosen as target force during phase 2, the ramp-and-hold task.



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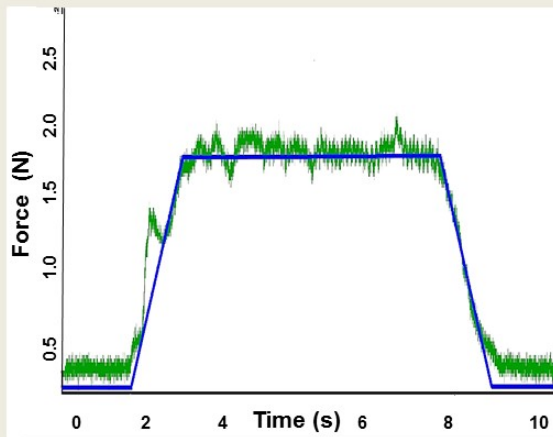
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Methodology



Ramp-and-Hold Phase

- Participants were instructed to trace a line that ramps up to 20% MVC and then maintain that force.
- Participants were prompted to pull the trigger and ramp up maintaining steady force for 6 s and then to slowly release the trigger.
- Various imperceptible noise levels were applied to the subject to determine which amplitude resulted in greatest force steadiness.



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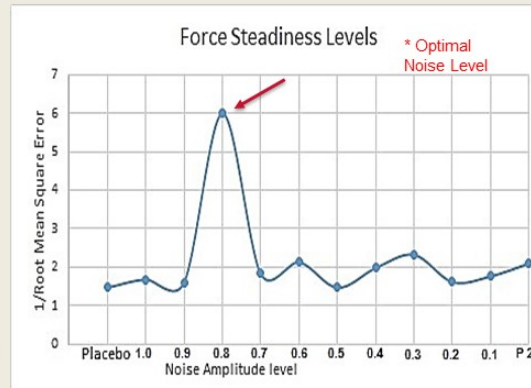
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Analysis and Results



Data Reduction (forearm placement)

- Root mean square error (RMSE) was calculated to determine the error between measured values of applied force and the actual force trace during the ramp-and-hold phase.
- Graphs were constructed using the inverse RMSE. (Mendez-Balbuena, 2012)
- Repeated measures t-test was performed to compare the RMSE with zero noise (placebo) and the RMSE with optimal noise.
- For analysis, statistical significance was set at 0.05.



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Results (forearm placement)

- Paired t-test was performed to compare the RMSE with zero noise and the RMSE with optimal noise values.

<u>Group</u>	<u>Placebo</u>	<u>Optimal Noise</u>
Mean	0.377	0.239
SD	0.1323	0.0423
SEM	0.0467	0.0149
N	8	8

($p = 0.0234$)

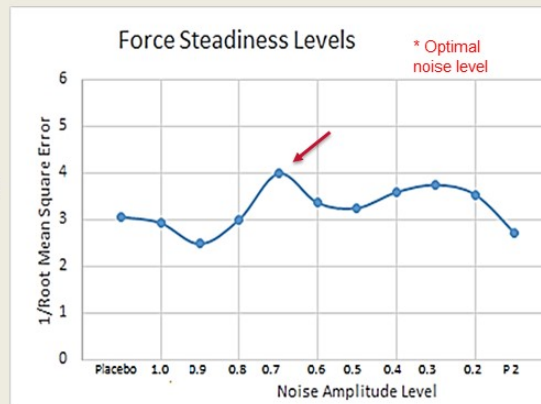
- Optimal noise values were **significantly** different than Placebo.

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Wrist placement

- RMSE was calculated to determine the error between measured values of applied force and the actual force trace during the ramp-and-hold phase.
- Pearson's correlation was performed on placebo amplitudes to test if a learning effect had appeared.
- Repeated Measures t-test was performed to compare the RMSE with zero noise and the RMSE with optimal noise.
- For analysis, statistical significance was set at 0.05.



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Results (wrist placement)

- Paired t-test was performed to compare the RMSE with zero noise and the RMSE with optimal noise values.

Group	Placebo	Optimal Noise
Mean	0.410	0.273
SD	0.1365	0.0458
SEM	0.0488	0.0162
N	8	8

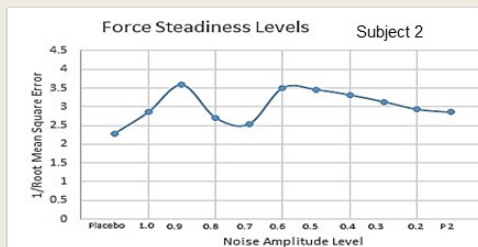
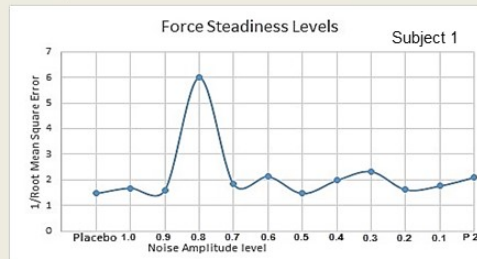
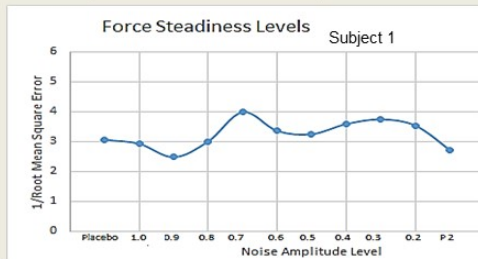
(p = 0.017)

- Optimal noise values were significantly different than Placebo.



Wrist Placement

Forearm Placement





Paired t-test

- Paired t-test was performed to compare Optimal Noise (ON) level values from wrist placement and ON values from forearm placement between participants.

Results

<u>Group</u>	<u>Wrist ON</u>	<u>Forearm ON</u>
Mean	0.273	0.239
SD	0.0436	0.0383
SEM	0.0154	0.0135
N	8	8

DF = 7, M = 0.018
p = (0.102)

- Force steadiness in the optimal noise condition was **not significantly different** between wrist placement and forearm placement.

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Military

- Applying imperceptible noise levels to increase force stability could yield many benefits to aid our Soldiers in tasks that require fine motor control.
- Further research could be conducted on how this technique can be applied and improve performance in other military applications.
 - Shooting

Civilian

Using imperceptible noise levels to increase force steadiness could also benefit many different areas in the civilian sector such as:

- Surgeons
- Sports

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- Kouzaki, M., Kimura, T., Yoshitake, Y., Hayashi, T., & Moritani, T. (2012). Subthreshold electrical stimulation reduces motor unit discharge variability and decreases the force fluctuations of plantar flexion. *Neuroscience letters*, 513(2), 146-150.
- Mendez-Balbuena, I., Manjarrez, E., Schulte-Mönting, J., Huethe, F., Tapia, J. A., Hepp-Reymond, M. C., & Kristeva, R. (2012). Improved sensorimotor performance via stochastic resonance. *The Journal of Neuroscience*, 32(36), 12612-12618.
- Moss, F., Ward, L. M., & Sannita, W. G. (2004). Stochastic resonance and sensory information processing: a tutorial and review of application. *Clinical neurophysiology*, 115(2), 267-281.



The author wishes to thank Dr. Matthew Tenan and Dr. Courtney Webster for their guidance and expertise.

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A Systematic Study of the Electrical Properties of Organic Ballistic Gelatin

Ben Burke
University of Maryland, College Park
Major: Biological Sciences
RSQ-HRED

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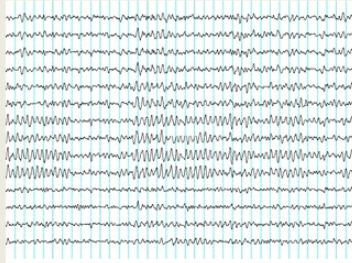


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Outline

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- Background
 - What is electroencephalography? What is a phantom?
- Methods
 - What variables were tested? How were these variables tested?
- Results
 - How do these variables affect the gelatin?
- Discussion
 - What are the next steps for this research?



Citation: <https://upload.wikimedia.org/wikipedia/commons/5/5f/ElectroEncephalogram.png>

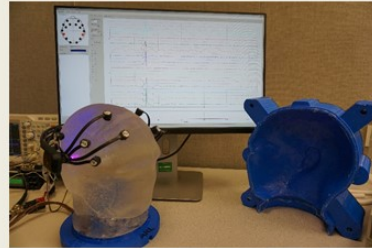
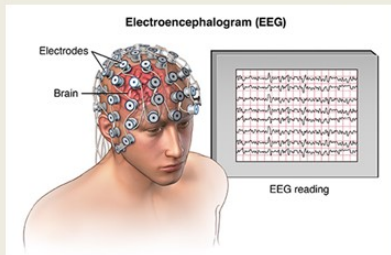
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- Electroencephalography (EEG) is the measurement of brain activity via electric potentials at the scalp.
- EEG allows researchers to understand cognitive effects of various tasks.
- Phantom-electrical surrogate with known signal and composition that can be used to verify EEG devices.
 - Currently no inexpensive, standard phantom recipe or material.



Citation: <https://api.kramesstaywell.com/Content/6066ca30-310a-4170-b001-a4ab013d61fd/medical-illustrations/Images/pnerv20140331v0001> 3



- Organic ballistic gelatin can be used to simulate human tissue due to its electrical and mechanical properties.
- Ballistic gelatin is already conductive to electricity.
 - No in-depth study of electrical properties of ballistic gelatin
- The purpose was to determine the extent to which the electrical properties of ballistic gelatin can be controlled.



Citation: <http://www.thefirearmblog.com/blog/wp-content/uploads/2015/11/IMG1758.jpg> 4



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Methods

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- Designed a frame setup for producing perfectly flat, equally sized samples
- Developed a process for mixing gelatin samples
- Used LCR meter to take resistance and capacitance readings of each sample
- Experimented with independent variables during mixing



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Methods (cont.)

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- Independent variables tested during this project:
 - Directly impacted material composition:
 - Density
 - Salinity
 - Indirectly impacted material composition:
 - Warm-up time inside/outside frame
 - Mixing time



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Results (Density)



	Resistance		Capacitance	
	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>
Frequency	4034.92	<0.001	5.441	0.00482
Density	34.93	<0.001	1.280	0.27804
Frequency*Density	36.25	<0.001	16.468	<0.001

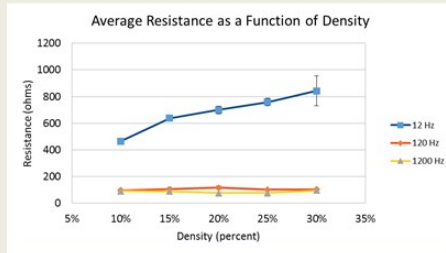
A 2-way ANOVA was performed with frequency and density as independent variables.

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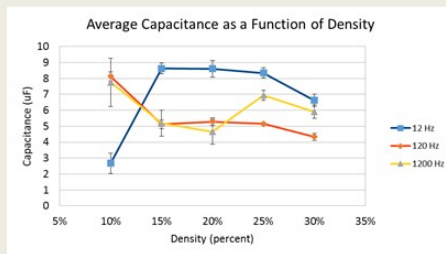


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Results (Density) (cont.)



Resistance increased as density increased
Noticeably at lower frequency levels



Inconclusive effect of density on capacitance
Capacitance decreased as frequency increased

Key point: Density has a relatively limited effect.

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Results (Salinity)



	Resistance		Capacitance	
	F	p	F	p
Frequency	2402.02	<0.001	693.344	<0.001
Salinity	827.79	<0.001	560.169	<0.001
Density	11.09	<0.001	0.143	0.7053
Frequency*Salinity	451.54	<0.001	192.248	<0.001
Frequency*Density	11.92	<0.001	1.024	0.3599
Salinity*Density	53.37	<0.001	2.993	0.0307
Frequency*Salinity*Density	43.65	<0.001	1.099	0.3621

A 3-way ANOVA was performed with frequency, salinity, and density as independent variables.

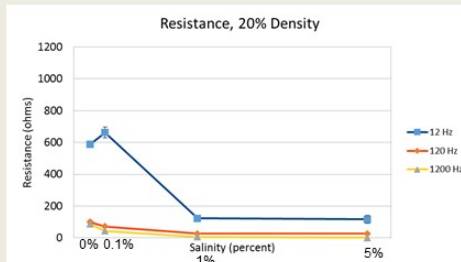
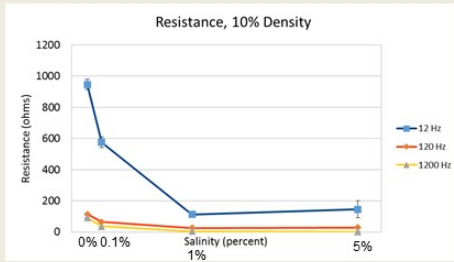
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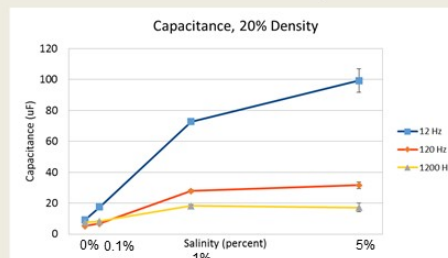
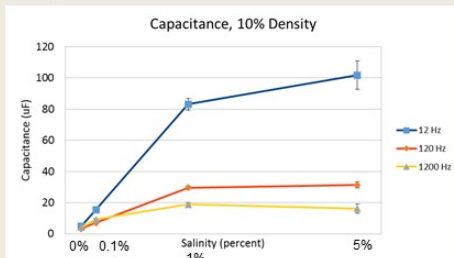


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Results (Salinity) (cont.)



Resistance tended to decrease as salinity increased across all density levels.
Capacitance tended to increase as salinity increased across all density levels.

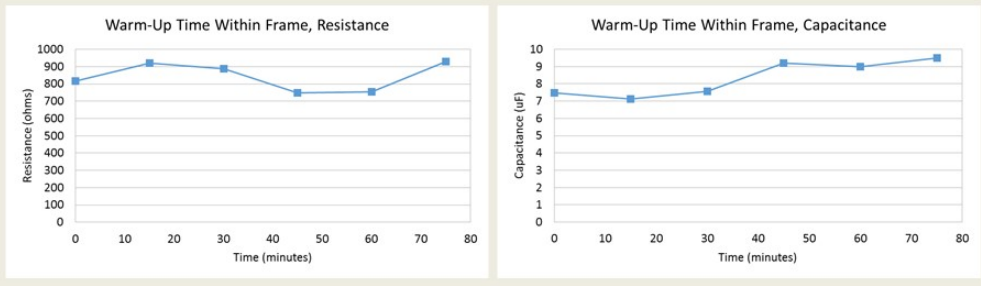


Key point: Salinity has a clear effect.

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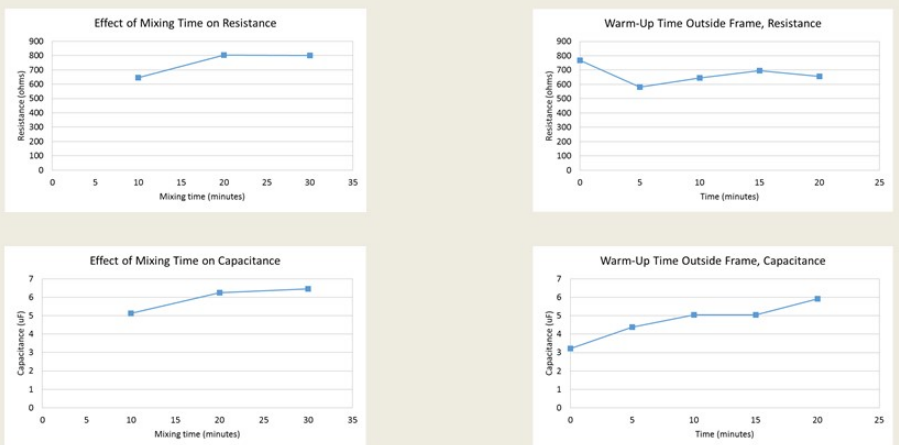
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- Increase in warm-up time led to inconclusive effect on resistance and increase in capacitance.



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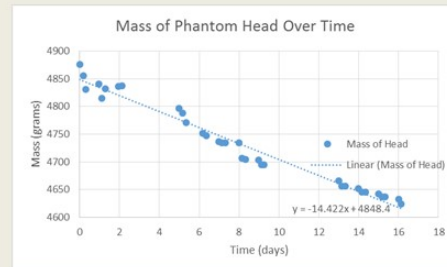
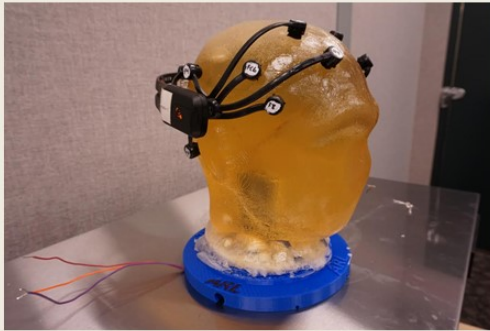
- Increased mixing time and warm-up time had contradictory effects on resistance.
- Increased capacitance as mixing time and warm-up time increased.



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- Weighed a finished head (20% density, 5% salinity) over a 16-day period to observe loss in mass
- 5.17% of original mass lost over the period
- Average loss of original mass per day of 0.3%



The mass of the phantom head over a period of almost 400 h

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- Density and salinity can be changed to improve resistance and capacitance.
- Salinity has greater effect than density.
- Increasing density to increase firmness can be counteracted by increasing salinity to lower resistance.
- Loss of gelatin mass over time is an issue, but changes to density can be anticipated.



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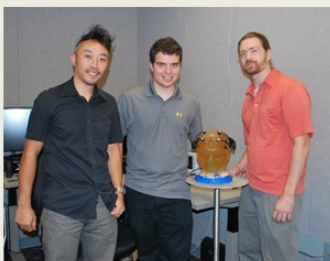
- Future research will focus on utilizing head for testing.
- Need to look for an alternative, longer-lasting material.
 - Synthetic gelatin
 - Carbon nanofilaments



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- Main takeaways:
 - Density and salinity can be changed to tune electrical properties.
 - Organic gelatin can be used for a phantom head.
 - Other variables and materials need to be tested.
 - Immediate, real-world applications for this research.
- Any questions?



Citation: <http://www.arl.army.mil/www/articles/2644/image.1.jpg>

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Sensors and Electron Devices Directorate (SEDD)

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Statistical Analysis of Atmospheric Corrections for UAS Acoustic Signals

Minas Benyamin
University of Maryland at College Park
Electrical Engineering: Graduate 2016

Mentor: Geoffrey Goldman
SEDD/SIP
Acoustic and E&M Sensing Branch

Approved for public release; distribution unlimited

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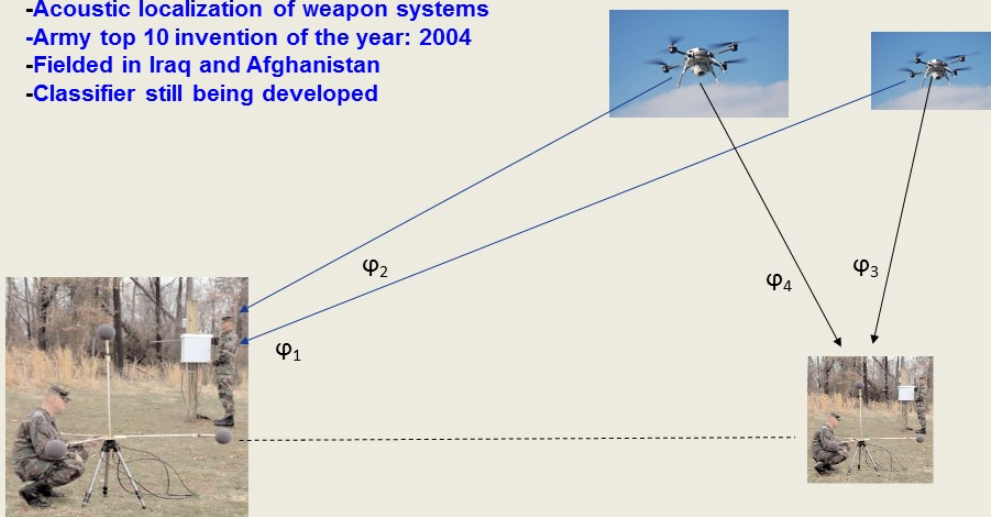
Motivation: Improved
Classification for UTAMS

ARL

Unattended transient acoustic MASINT System (UTAMS)

- ARL-developed system
- Acoustic localization of weapon systems
- Army top 10 invention of the year: 2004
- Fielded in Iraq and Afghanistan
- Classifier still being developed

Estimate target location
by triangulation



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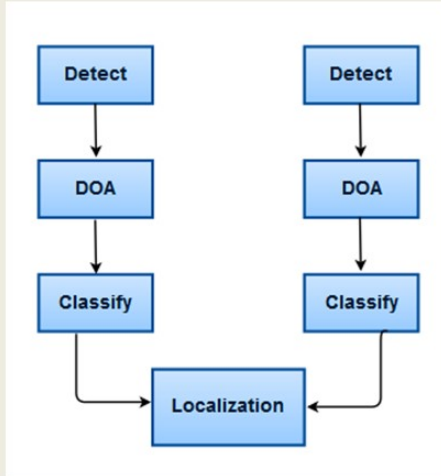


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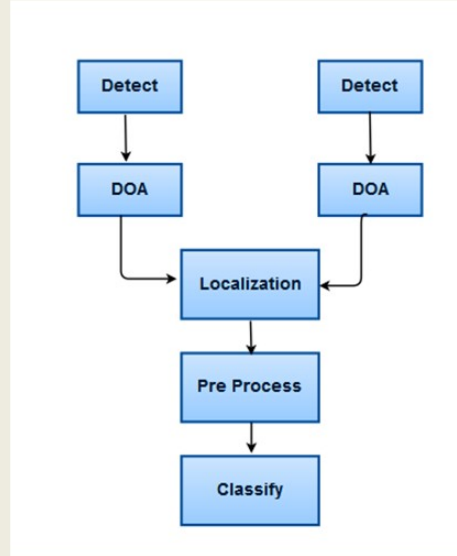
New Classifier Architecture



UTAMS signal processing architecture



Proposed signal processing architecture



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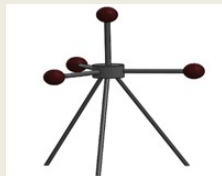
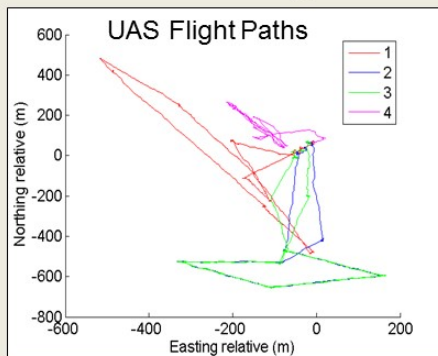


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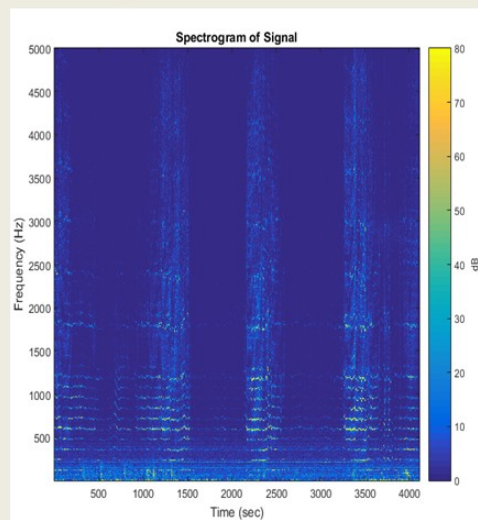
Acoustic UAS Data Collection



Class I Gasoline Powered UAS acoustic data was obtained from Webster Field using a small tetrahedral array.



Small tetrahedral microphone array



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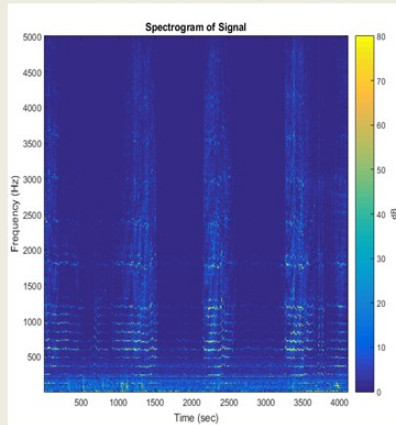
Doppler Correction



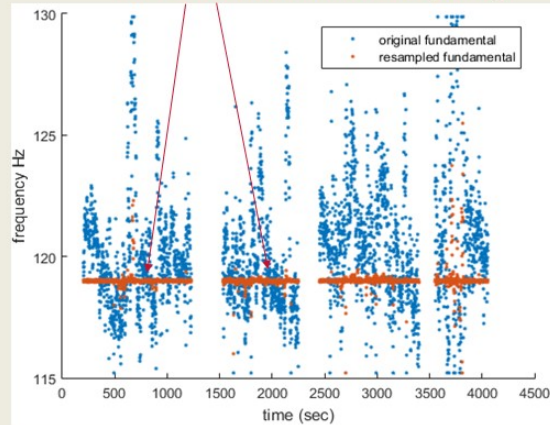
Fundamental frequency was calculated for each block of time using autocorrelation-based approach.

Data was resampled to have a consistent fundamental frequency.

Uncorrected spectrum



Corrected fundamental frequency



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Effect of Acoustic Propagation



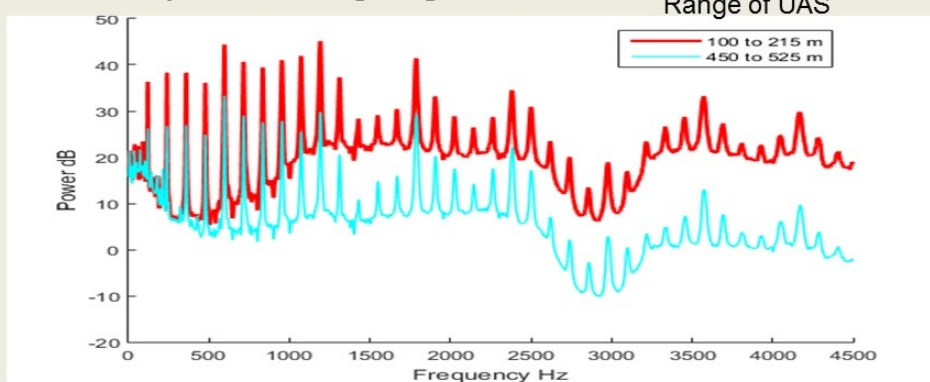
Spherical Spreading

- Amplitude drops as a factor of $1/\text{Range}$.

Frequency Attenuation

- Atmosphere acts like a low pass filter dependent on the humidity, temperature, and pressure.

UAS Spectra: Average Signal Power



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Model of the Acoustic Channel



$$y(t) = h(t) \otimes x(t) + n(t)$$

$$Y(\omega) = H(\omega) \cdot X(\omega) + N(\omega)$$

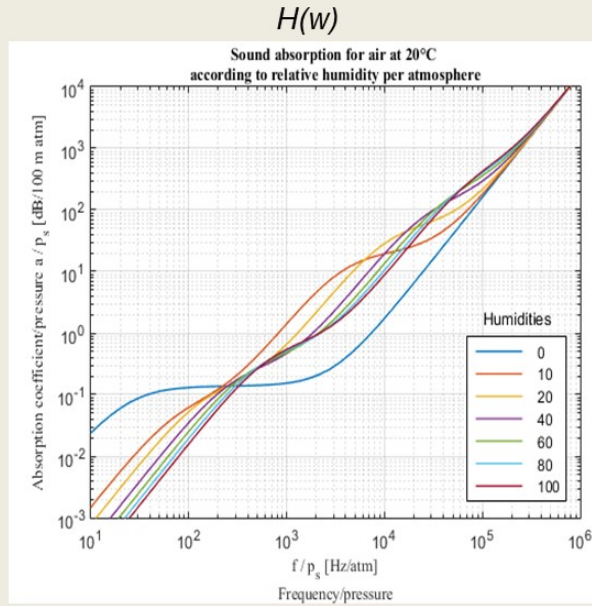
$y(t)$ – time dependent measured signal

$x(t)$ – true signal $n(t)$ – noise

$h(t)$ – convolution term of atmosphere

$Y(\omega)$ – frequency domain signal

$H(\omega)$ – frequency response of atmosphere



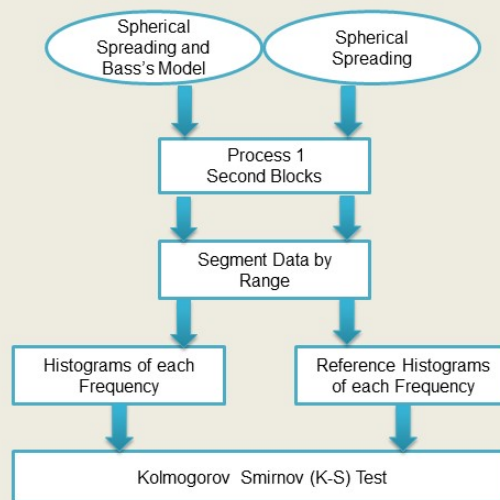
Bass, Sutherland, Zuckerwar, Blackstock, Hester,
[Atmospheric absorption of sound: Further
developments](#), J. Acoust. Soc. Am. Volume 97, Issue
1, pp. 680-683, January 1995

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Statistical testing of acoustic data at different ranges



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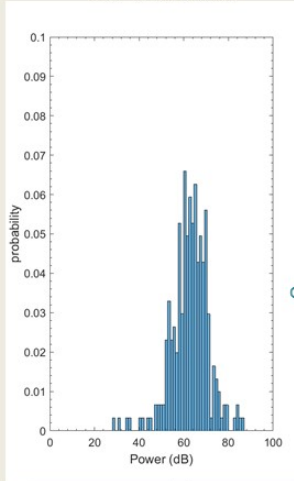


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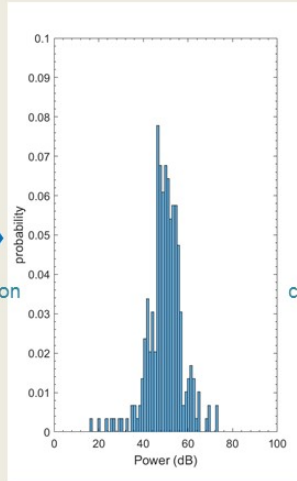
Histograms of UAS for the 2nd Harmonic at 242 Hz



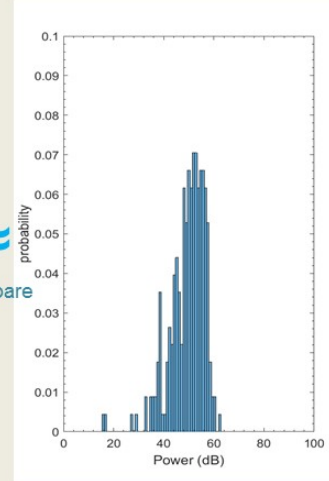
Original Power PDF
for 1 to 72.5 m



Fully Corrected PDF at
reference range at 241 m



Reference PDF at
range of 241 m



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Two-Sample Kolmogorov-Smirnov (K-S) Test



Statistical Test to test for the likelihood that 2 distributions are the same

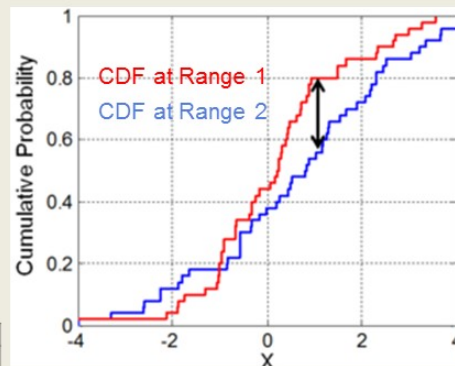
$$H_0: F_{1,n}(x) = F_{2,m}(x)$$

$$H_1: F_{1,n}(x) \neq F_{2,m}(x)$$

$$D_{n,m} = \max |F_{1,n}(x) - F_{2,m}(x)|$$

$$D_{n,m} > c(\alpha) \sqrt{\frac{n+m}{n \cdot m}}$$

α	0.10	0.05	0.025	0.01	0.005	0.001
$c(\alpha)$	1.22	1.36	1.48	1.63	1.73	1.95



Null Hypothesis is rejected with probability $1-\alpha$ for Empirical
Cumulative Distribution Functions F_1 and F_2

Justel, A.; Peña, D.; Zamar, R. (1997). "A multivariate Kolmogorov-Smirnov test of goodness of fit".
Statistics & Probability Letters 35 (3): 251-259.

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Noise reduction using Spectral Subtraction



Motivation: $Y(\omega_i) = H(\omega_i) \cdot X(\omega_i) + N(\omega_i)$

$$X(\omega_i) = \frac{Y(\omega_i)}{H(\omega_i)} - \frac{N(\omega_i)}{H(\omega_i)} \leftarrow \text{Potentially quite large}$$

Spectral Filter: $\hat{X}(\omega_i) = \frac{Y(\omega_i)}{H(\omega_i)} \cdot \frac{|Y^2(\omega_i) - \overline{N^2(\omega_i)}|}{|Y^2(\omega_i)|}$

For all ω_i such that $Y^2(\omega_i) \ll \overline{N^2(\omega_i)}$ then for those frequencies ω_i

$$\hat{X}(\omega_i) = 0$$

BOLL S.F (1979) Suppression of Acoustic Noise in Speech Using Spectral Subtraction. IEEE Tran. on Acoustics, Speech and Signal Processing ASSP-27, 2, pp. 113-120.

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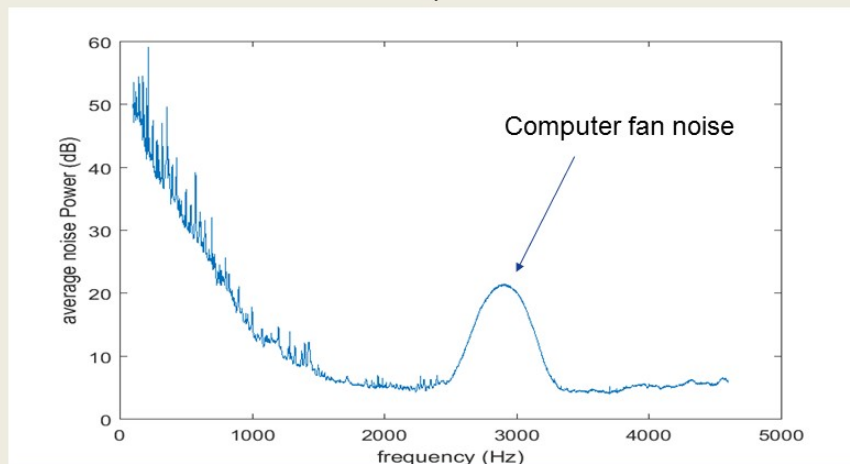
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Average Noise Power



- Estimate was computed from average spectral power of background environment.
- Measurements were taken when the UAS was off (Measurements vary with time and location).

Noise Spectrum



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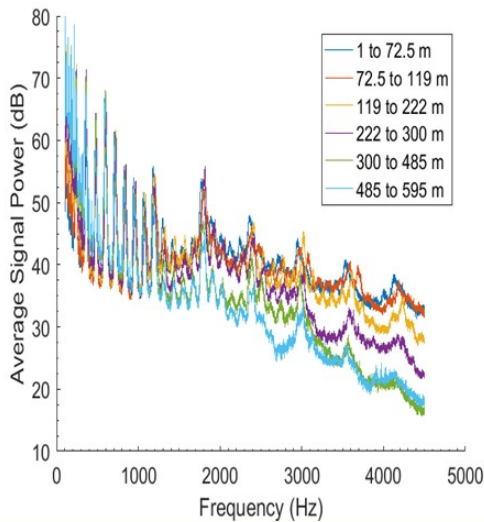


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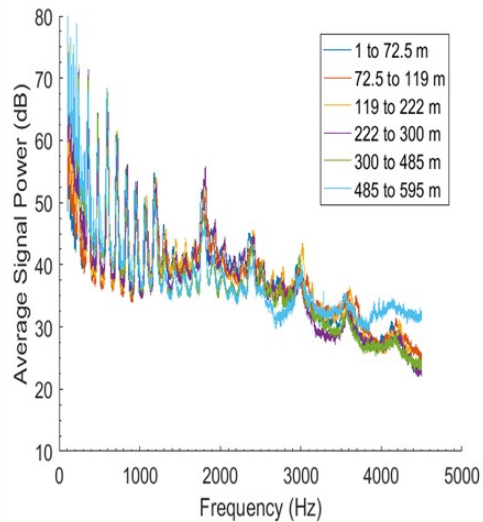
UAS Spectra Comparisons



Correction for Spherical Spreading



Correction for Spherical Spreading and atmospheric attenuation



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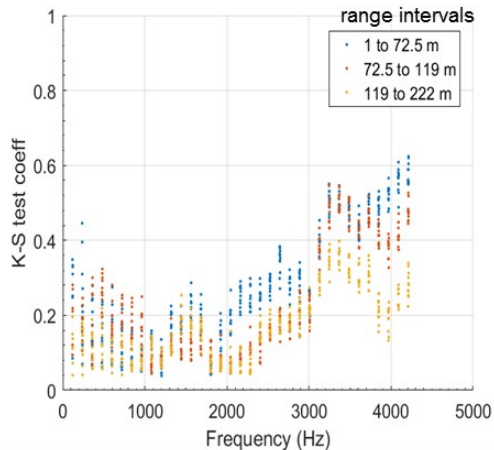


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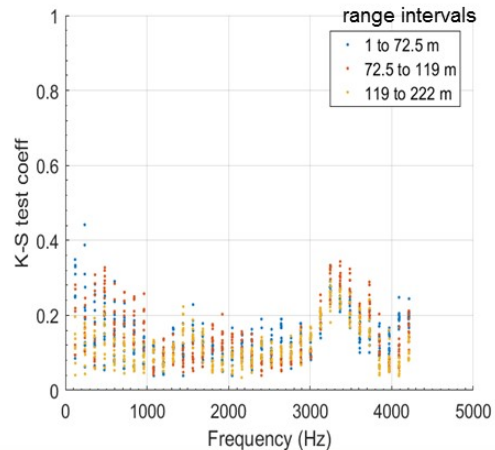
Kolmogorov Smirnov Test Near Range Comparison



Spherical Spreading correction



Atmospheric and Spherical Spreading correction



- Frequencies of Interest: Signal Harmonics and Adjacent Frequencies within ± 5 Hz
- Lower Coefficients values indicate estimated PDFs are more likely to match
- Near Range < 222 m

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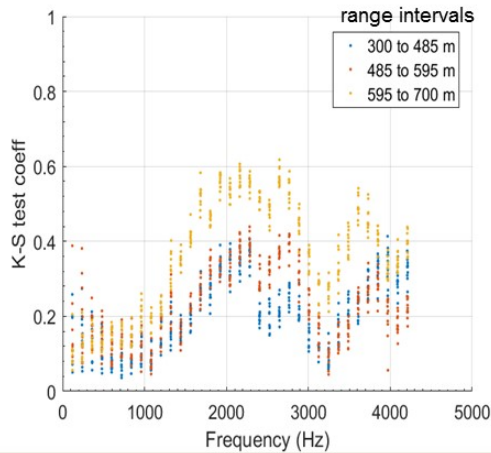


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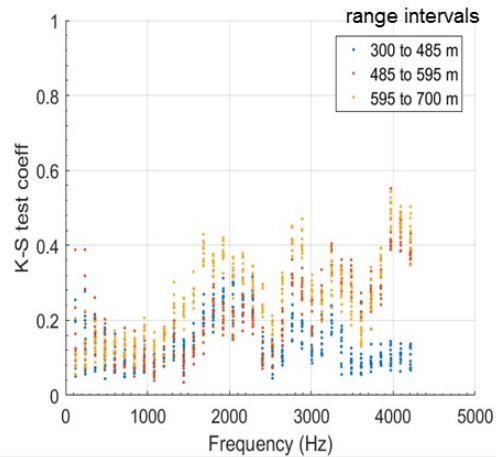
Kolmogorov Smirnov Test Far Range Comparison



Spherical Spreading correction



Atmospheric and Spherical Spreading correction



- **Frequencies of Interest: Signal Harmonics and Adjacent Frequencies within 5 Hz**
- **Lower Coefficients values indicate estimated PDFs are more likely to match**
- **Far Range > 300 m**

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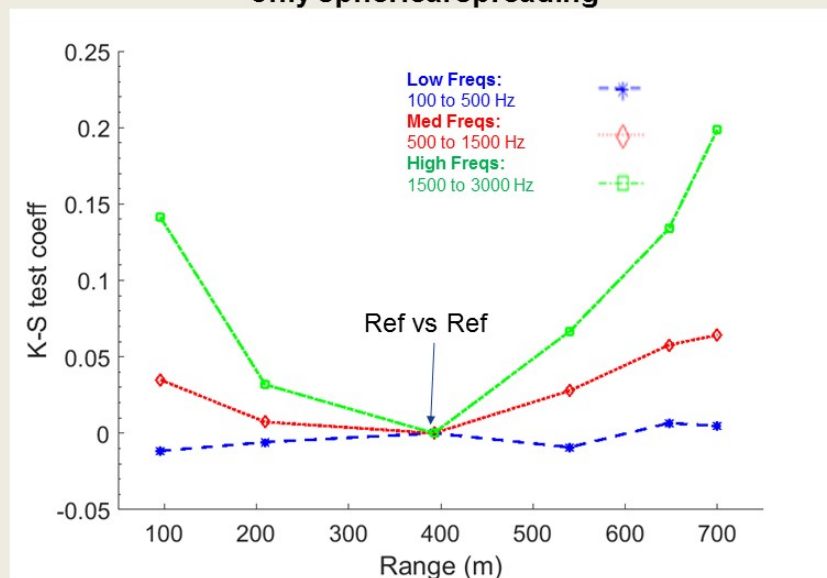


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K-S Test Aggregate Results



Average improvement in K-S value between full correction and only spherical spreading



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Conclusion



- Preprocessing algorithm was developed to improve the results of acoustic classification algorithms.
 - Bass's model was used to correct for the frequency response of the atmosphere.
 - To avoid amplifying noise, spectral subtraction was implemented using Boll's algorithm (requires background measurement).
- By correcting for atmospheric attenuation and spherical spreading
 - Low frequency KS test results slightly improved.
 - High frequency KS test results had larger improvements.
 - Long ranges had larger improvements.
- Classifier performance should slightly improve at shorter ranges with greater improvement at long ranges.
- Future work
 - Test algorithm using a UAS classifier
 - Test other metrics such as Kullback-Leiber divergence

Questions?

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Backup slides



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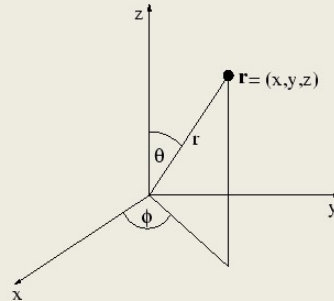
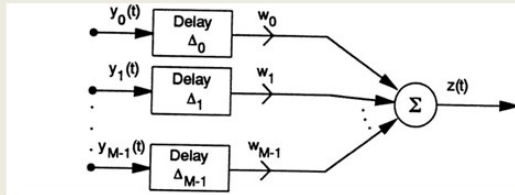
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Spatial Filtering



Delay and Sum Beamforming

$$a = [\cos \theta \cos \phi \quad \cos \theta \sin \phi \quad \sin \theta]^T$$



Time Delay $\tau_i = \frac{a^T p_i}{c}$; $p_i = [x_i \ y_i \ z_i]^T$ With wave speed 'c'

Improves SNR and suppress interference

Jian Li, and Petre Stoica, eds. Robust adaptive beamforming. New Jersey: John Wiley, 2006

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Alternative Statistical Testing



Other Divergence Tests

Multidimensional KS Test

- Idea to use harmonics to add dimensions
- Wanted a fast metric concerns about processing time

Kullback-Leiber

- CDFs converge faster than PDFs

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Outline



- **Motivation**
- **Signal Processing**
- **Results**
- **Conclusion**

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Estimating Signal



Signal Model

$$y(\omega) = x(\omega) + n(\omega)$$

Spectral Subtraction

$$\hat{x}(\omega) = \frac{y(\omega)^2 - E(N^2)}{y(\omega)^2} (y(\omega))$$

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Frequency Response of Atmosphere



$$H(\omega) = \frac{10^{-a}}{\Delta R}$$

$$hum = p_{s0} \frac{h_r}{p_s} \cdot \frac{p_{sat}}{p_{s0}} \% \quad p_{sat} = p_{s0} \cdot 10^{-6.8346 \left(\frac{T_r}{T}\right)^{1.264} + 4.6151} (atm)$$

$$F_{r,o} = \frac{1}{p_{s0}} \left(24 + 4.04 \cdot 10^4 h \frac{0.02 + hum}{0.391 + hum} \right) \frac{Hz}{atm}$$

$$F_{r,N} = \frac{1}{p_{s0}} \left(\frac{T_o}{T} \right)^{\frac{1}{2}} \cdot \left(9 + 280h \cdot e^{-4.17 \left(\frac{T_o}{T} \right)^{\frac{1}{2}} - 1} \right) \frac{Hz}{atm}$$

$$\frac{a}{p_s} = \frac{20}{\ln 10} \cdot \frac{F^2}{p_{s0}} \left(1.84 \cdot 10^{-11} \cdot \left(\frac{T}{T_o} \right)^{1/2} + \left(\frac{T}{T_o} \right)^{-5/2} \cdot \left[0.01278 \cdot \frac{e^{-2239.1/T}}{F_{r,o} + F^2/F_{r,o}} + 0.1068 \frac{e^{-3352/T}}{F_{r,N} + F^2/F_{r,N}} \right] \right) \frac{dB}{m \cdot atm}$$

p_{s0} – reference atmospheric pressure (atm)

p_s – atmospheric pressure (atm)

f – acoustic frequency (Hz)

T_o – reference temperature (273.16 K)

T – temperature

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Motivation



UASs are low-cost asymmetric threats

- Can easily be fitted with sensors and even weapon systems



UAS defeat

- Poor identification would lead to potential fratricide

Classification of UASs remains a persistent challenge

- Classifiers are often based on feature matching
- Features can change with propagation through the atmosphere



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ARL

Joule Heating Thin Film NiTi Cantilevers

Merric Srour, 2nd Summer

Senior in Mechanical Engineering at UMBC

Mentors: Cory Knick, Gabriel Smith

August 11, 2016



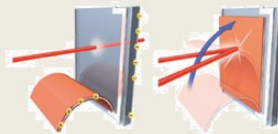
Motivation



Application:

- MEMS Shutter
 - Device Protection
- Low power on-chip actuation
- Robotics Actuation

MEMS Micro-Shutter



Passive MEMS Shutter Concept

Problem:

- Requires small form factor, i.e. radius of curvature ($\sim 10\mu\text{m}$)
- Needs quick ($< 100\text{ms}$) and low power actuation
- Material properties
 - Maintaining shape memory effect in nano-scale films

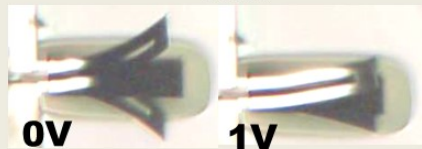
Micro-Shutter array

Passive



Active

My Focus: Demonstrating joule heating active actuation method and modeling device bending





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Presentation Outline



1. NiTi background
2. Previous NiTi characterization
3. Passive actuation methods
4. Active joule heating actuation method (my summer research)
5. Modeling radius of curvature
6. Summary and future work

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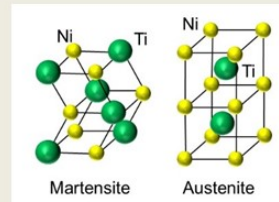
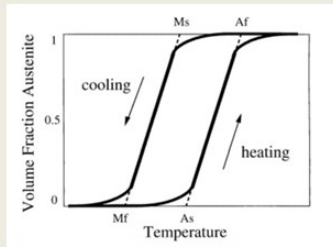


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NiTi Background



- Nickel Titanium (NiTi) is a Shape Memory Alloy (SMA), meaning it is a type of metal alloy that can recover seemingly permanent strain when heated.
- SMAs and, specifically, NiTi have 2 phases - martensite and austenite.
 - Martensite : Low temperature phase (ductile)
 - Austenite : High temperature phase



Tools to characterize NiTi :

- Differential Scanning Calorimetry (DSC)
- X-ray Diffraction (XRD)
- Wafer Bow Tool
 - Stress vs. Temperature using

$$\text{Stoney's equation: } \sigma = \frac{E}{6(1-\nu)} \frac{h_s^2}{h} \left(\frac{1}{R} - \frac{1}{R_0} \right)$$

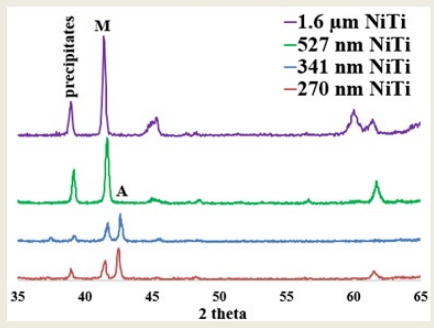
Kahn H, Huff MA, Heuer AH. The TiNi shape-memory alloy and its applications for MEMS. J. Micromech. Microeng. 1998;8:213-221.

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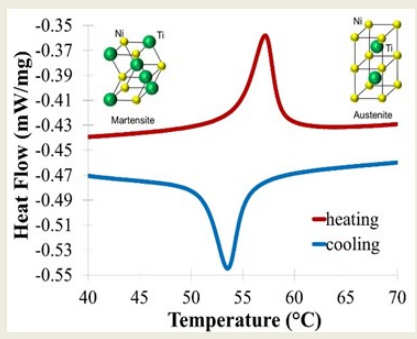
Previous characterization of NiTi material

XRD Data Comparing Varying Thicknesses of NiTi



- Primary martensite peak : 41.5°
- Primary austenite peak : 42.5°

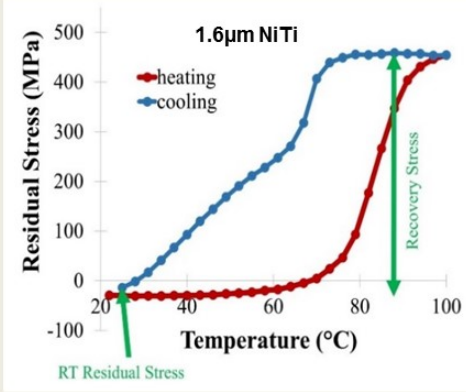
DSC Full Heat/Cool Cycle



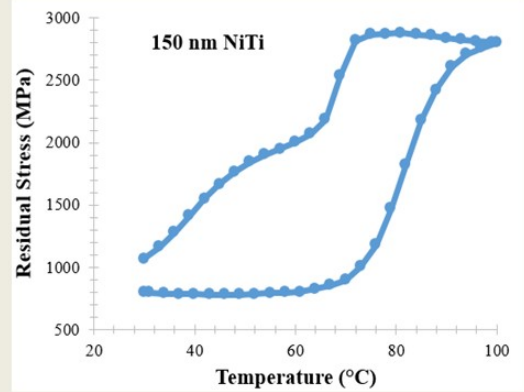
- Reversible phase change above RT ~58°C

Previous characterization of NiTi material :

Stress vs. Temperature for NiTi on Si

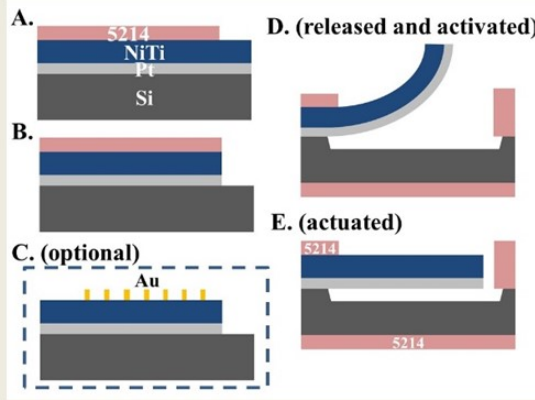


- Completely reversible
- Large recovery stress
- Low residual stress



- Reversible
- Large recovery stress

Process for building NiTi Devices



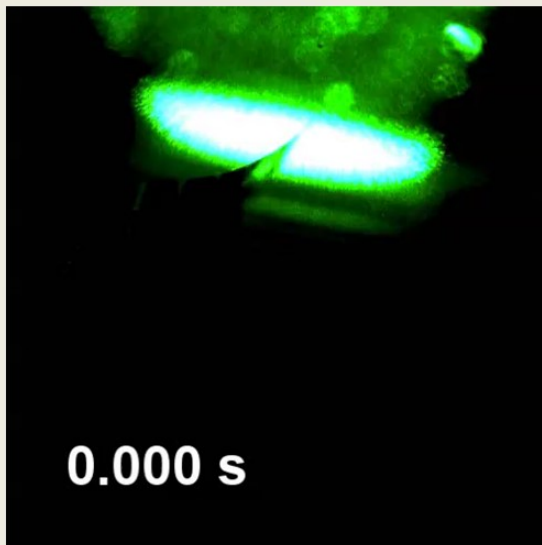
- When released, cantilevers curl up due to stress in bimorph layer (Pt / NiTi).
 - CTE mismatch, and cooling from 600°C deposition or anneal temperature

- When NiTi is actuated, it goes from martensite to austenite phase, doubling in rigidity, and goes to its shape remembered state.

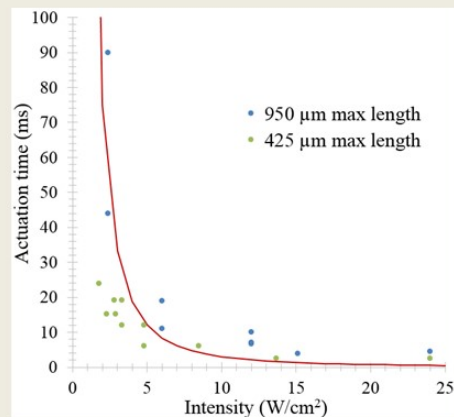
- 1- Pt evaporation and NiTi sputter
- 2- NiTi wet etch, and Pt ion mill using 5214 pattern
- 3 - Xenon Difluoride dry release from Si wafer
- 4 - Thermal actuation (laser, joule heating, etc.)

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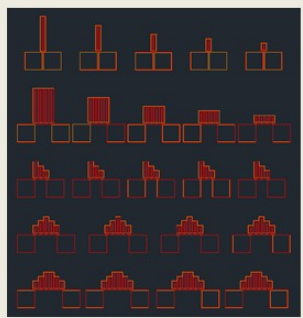
Laser Actuation Demonstration



Laser Intensity vs. Actuation Time

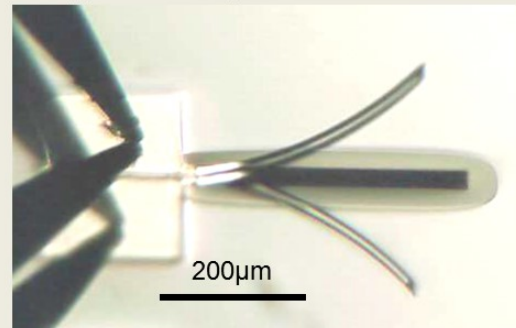


Previously had actuated the cantilevers using heater and laser, now actuating the devices using joule heating.



Device Design in AutoCAD

- 3 arrays with different width cantilevers
 - 20 μ m , 15 μ m , 10 μ m



Advantages of joule heating :

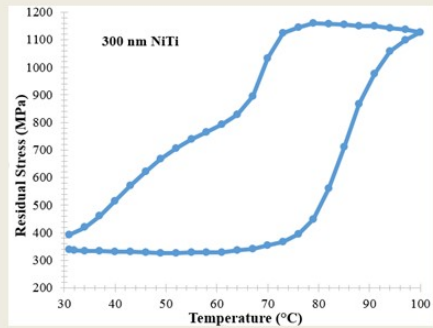
- Increases potential on chip applications
 - MEMS Sensing / actuating
 - Switching
 - Low power
- Ability to resonate actuators
 - Find thin film NiTi limits

Device Recipes

NiTi Thickness (nm)	Deposition Temperature (°C)	Post Anneal (600°)
600	600	No
300	600	Yes
300	600	No
300	400	Yes
300	400	No

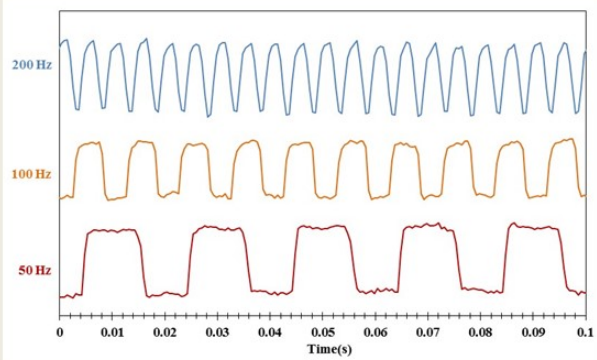
*All NiTi was sputtered on a 20 nm layer of Pt

Reason for trying 300 nm @ 400 °C



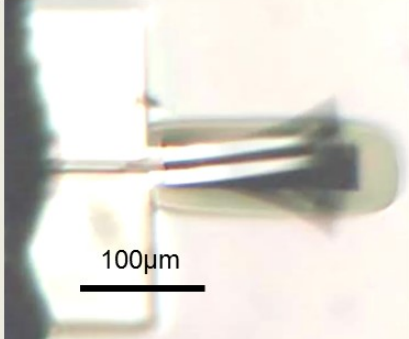
- Reversible 300 nm NiTi film on Si

Frequency Response



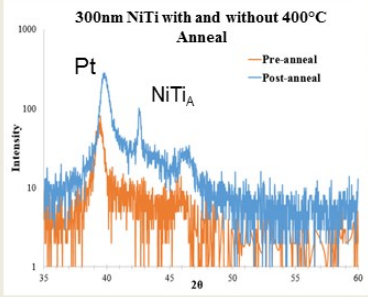
- Shows full range of motion up to 200 Hz
- Reduced range of motion up to 500 Hz

Device testing under Keyence microscope

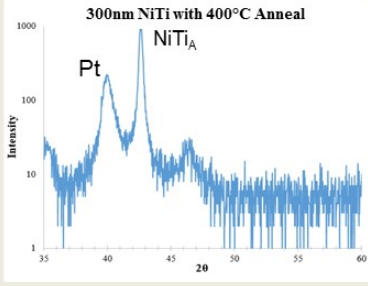
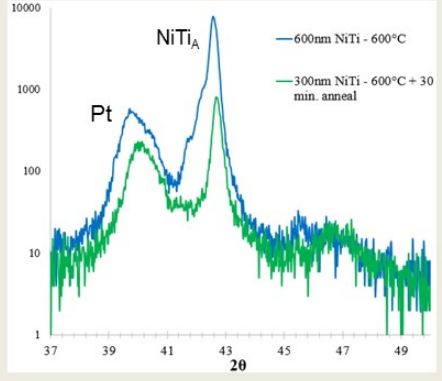


100 Hz recorded at 30 frames per second

Similar to the laser actuation, a full reversible cycle occurs within 3-5 ms



XRD of NiTi before and after 30 min Post anneal at 600 °C



NiTi sputter with immediate 30-min 600 °C post-anneal

- Made devices on both wafers
- Pt peak ~40.0°
- NiTi austenite peak ~42.5°

- Results confirmed crystallization of NiTi (required for shape memory effect)
- Working on correlating XRD data to device performance (Radius of Curvature, Recovery stress)



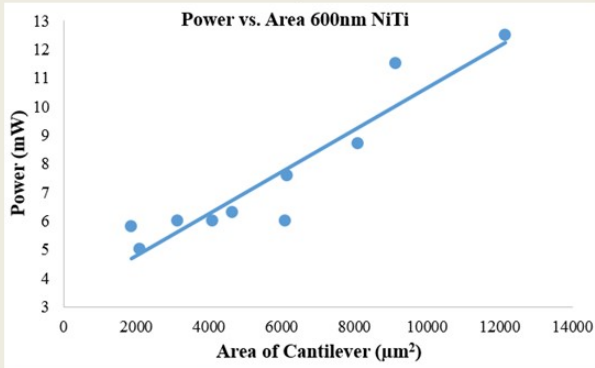
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Power Characterization

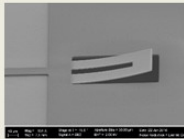


Single Cantilevers of 600 nm NiTi:

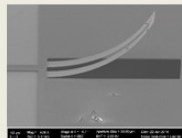
Summary Plot



- 5 mA current applied across cantilevers.
- As area increases, resistance increases; therefore, it requires more power to actuate.
- Requires 5 mW for 100 µm cantilever and 13 mW for 400 µm cantilever.



100 µm Length



400 µm Length



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Radius of Curvature Model



Equations to model the radius of curvature of a Bilayered Structure from Klein (2000):

$$\frac{1}{\rho} = k$$

$$\rho = \frac{-E'_{Pt} t_{Pt} E'_{NiTi} t_{NiTi} (t_{Pt} + t_{NiTi}) \Delta \epsilon_0}{G(E'_{Pt} t_{Pt} + E'_{NiTi} t_{NiTi})}$$

Where $\Delta \epsilon_0$ is a strain differential

$$G = E'_{Pt} t_{Pt}^2 \left(\frac{t_{NiTi} - t_{Pt}}{2} - \theta \right) - E'_{NiTi} t_{NiTi} \left[t_{Pt} \left(t_{Pt} + \frac{t_{NiTi}}{2} \right) + \frac{t_{NiTi}^2}{6} + \theta (2t_{Pt} + t_{NiTi}) \right]$$

Where θ is a correction factor used in the placement of the neutral plane

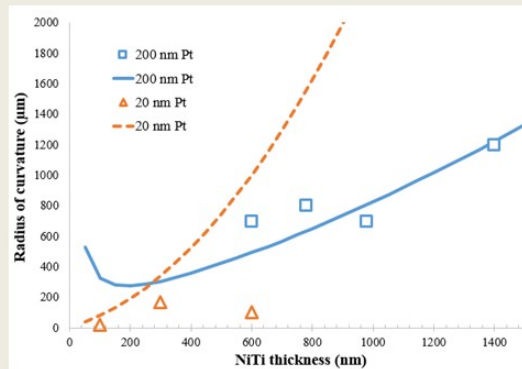
k = Radius of Curvature

ρ = Curvature

E'_x = Biaxial Modulus = $\frac{E_x}{(1-\nu_x)}$

t_x = Thickness of Layer

Material	CTE (ppm/K)	E Young's Modulus (GPa)	ν Poisson Ratio
NiTi (martensite)	6.6	83	0.33
Pt	8.8	168	0.38



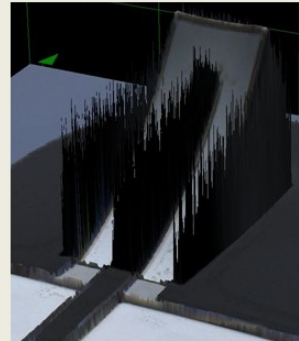
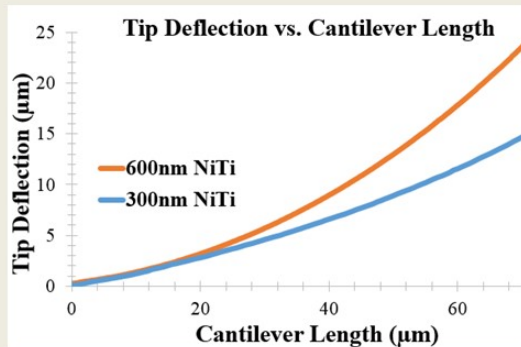
C. A. Klein and R. P. Miller, "Strains and stresses in multilayered elastic structures: The case of chemically vapor-deposited ZnS/ZnSe laminates," *Journal of Applied Physics*, vol. 87, no. 5, pp. 2265-2272, 2000.

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Radius of Curvature



Comparison between 300nm and 600nm NiTi radius of curvature:



LEXT 3D Microscope image of 600nm NiTi cantilever

$$k = \frac{1}{\rho} = \frac{L^2}{2d}$$

- ρ is the curvature
- **k is the radius of curvature**
- d is the deflection of cantilever at length L

k for 600nm NiTi = 105µm
k for 300nm NiTi = 167µm

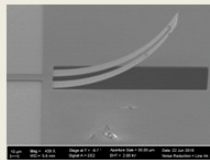
- Therefore, cantilevers at 600nm NiTi have a smaller radius of curvature (curl tighter) unlike model.

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Conclusions



- Joule Heater cantilevers respond with full range of motion up to 200 Hz (5 ms)
 - Determined upper bound of actuation at 500Hz
- Demonstrated first-time **5 mW** low power actuation
 - Opens up possibility of new applications space
- Reduced radius of curvature as tight as **105 µm compared to first-gen. 1.2 mm**
- Demonstrated full shape memory effect from devices at 600 nm and 300 nm NiTi
- Verified process requirement of > 400 °C for NiTi crystallization



Future studies:

- Continue making joule heated devices with reduced NiTi thickness
 - Smaller devices for MEMS applications
- Lower temperature NiTi deposition for process integration
- Already begun exploring alternative NiTi/SU8 stack
 - Model and preliminary tests show RC ~55µm
- Modeling radius of curvature of devices for arbitrary film stacks

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Acknowledgments

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- I would like to thank my mentors for their help throughout the summer.
- I would also like to thank Brian Isaacson for his help fabricating the NiTi devices.

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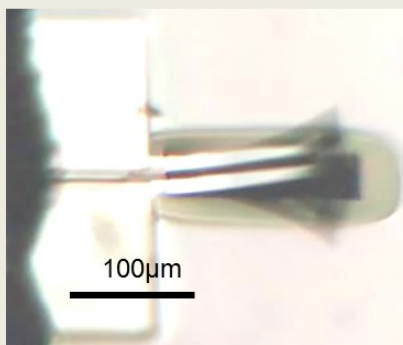
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Questions?



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Microcombustion and Thermophotovoltaics

Noah Zecher-Freeman
Power Components Branch
Mentor: Mike Waits

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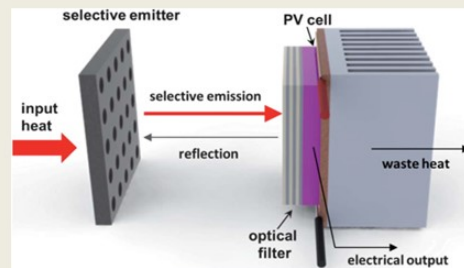
Soldier Power

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- Soldier is overburdened with weight, restricts mission length.
- Current lithium batteries have a specific energy of 160 Wh/kg.
- For 72-h mission, 20 W Soldier power requires 9 kg of batteries.
- Thermophotovoltaic (TPV) cells take advantage of the specific energy of hydrocarbons to reduce the weight carried by Soldiers.



Microreactor



$$\eta = \eta_{thermal} \cdot (\eta_{spectral} \cdot \eta_{vf} \cdot \eta_{PVcell})$$

$$= 50\% \cdot (70\% \cdot 25\%) = 8.8\% \text{ FY16 BPP Objective}$$

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Microreactors for TPV



Desirable Characteristics of TPV Microreactor:

- High Surface Area/Volume
- High, Uniform Temperature
- Complete Conversion
- Low Pressure Drop

Sizing a TPV Microreactor:

Irradiance of a grey body: ($\epsilon=0.8$) $T=1000\text{ C}$: $Q_{\text{rad}} = 11.9\text{ W/cm}^2$

Targeted power output $120\text{ W}_{\text{rad}}$

Surface area: $120\text{ W}/Q_{\text{rad}} \sim 10\text{ cm}^2$

Square shaped channel size: $(20 \times 20 \times 1)\text{ mm}$ $v_{\text{in}} \sim 10 \times s_L$

Bottom Line: The size of the system, nature of heat harvesting make it susceptible to **extinction and blowout**.

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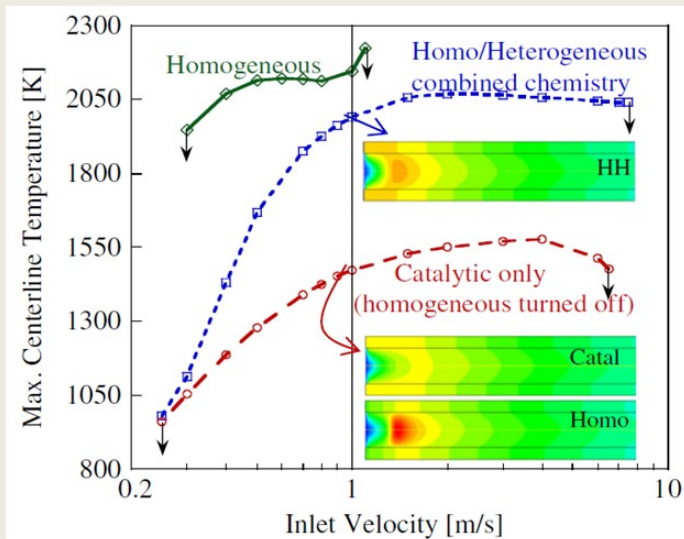
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Hybrid Homogeneous/ Heterogeneous Microreactors



Ind. Eng. Chem. Res., 45 (1), 2006

By combining both chemistries, we can:

- Breakdown fuel within a small residence time.
- Achieve a much larger operating window.

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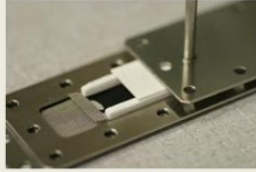
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Previous Microreactors



DSI reactor used to study the role of confinement

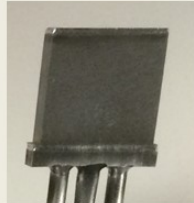
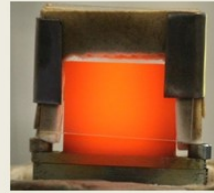
Tolmachoff, et al., *Applied Energy*, 2014



Frontiers MR 1.0 and 1.1 (FY14-FY15)

Studied performance with high heat loss & short residence times
Visualize gas reactions
Develop/validate reaction models: surface + gas-phase fuel decomposition

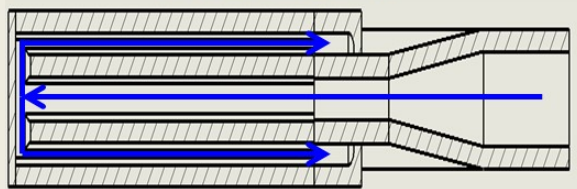
Tolmachoff et al., *Combust. Flame*, 2015



Frontiers MR 2.0 (FY16)

Adds heat recirculation
Validate reaction & CFD models
Operate in vacuum chamber

Frontiers MR 2.0 flow



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Previous Work

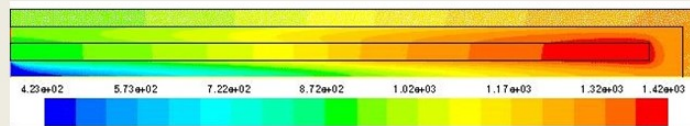
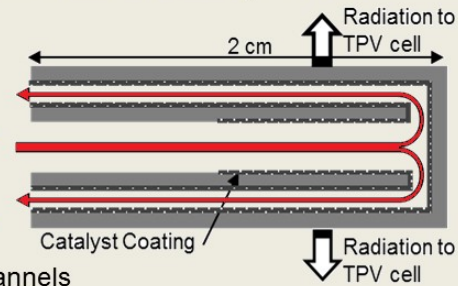


Previous modeling detailed how to maximize efficiency of reactor



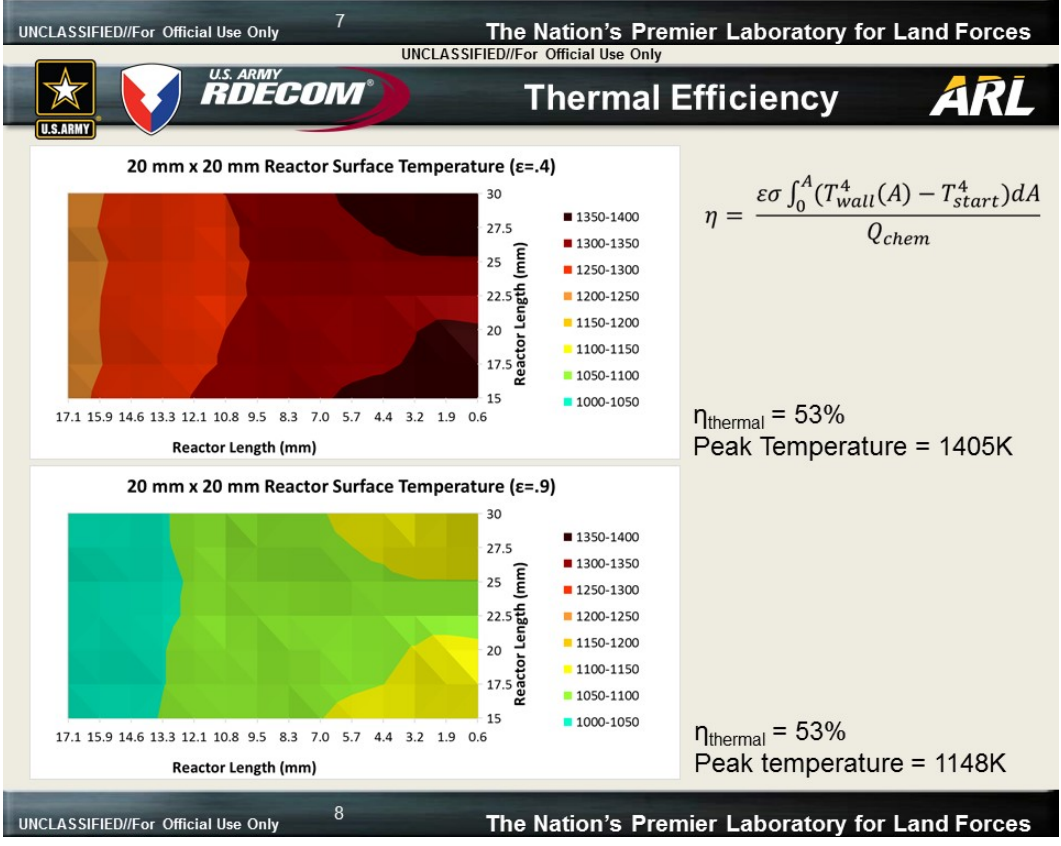
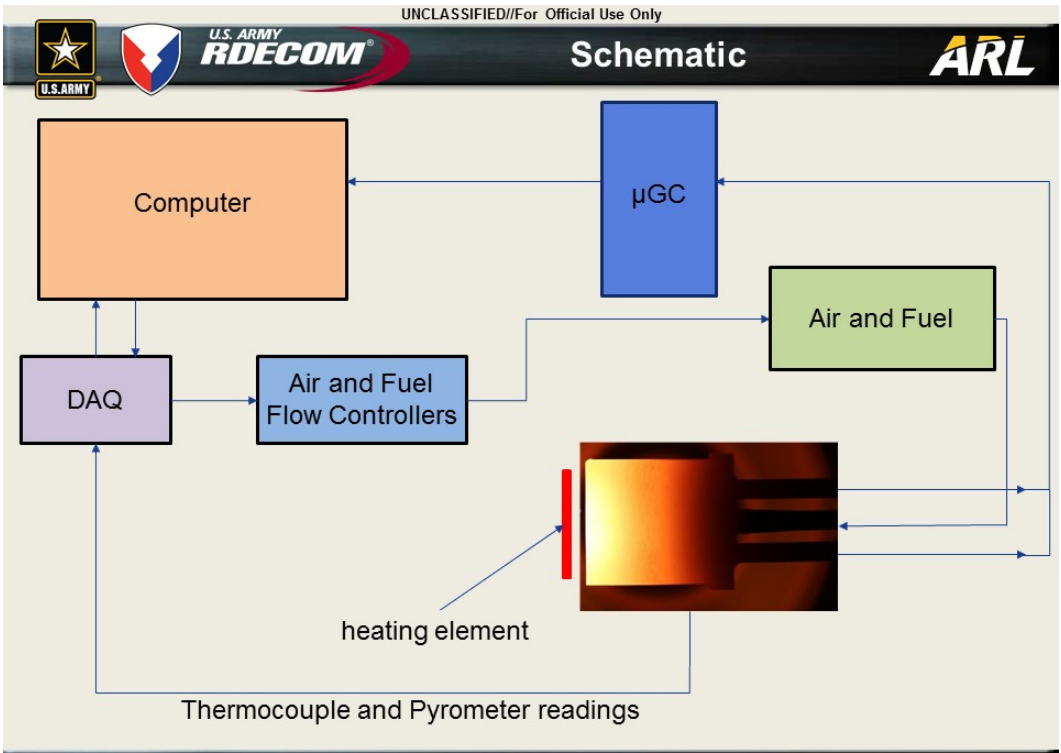
Energy balance:

- Combustion
- Desired surfaces
- Heat lost to exhaust
- Undesired surfaces
- Conduction along channels



[1] Tolmachoff et al., *Combustion and Flame*, 162 (2015), pp. 3674-3680.

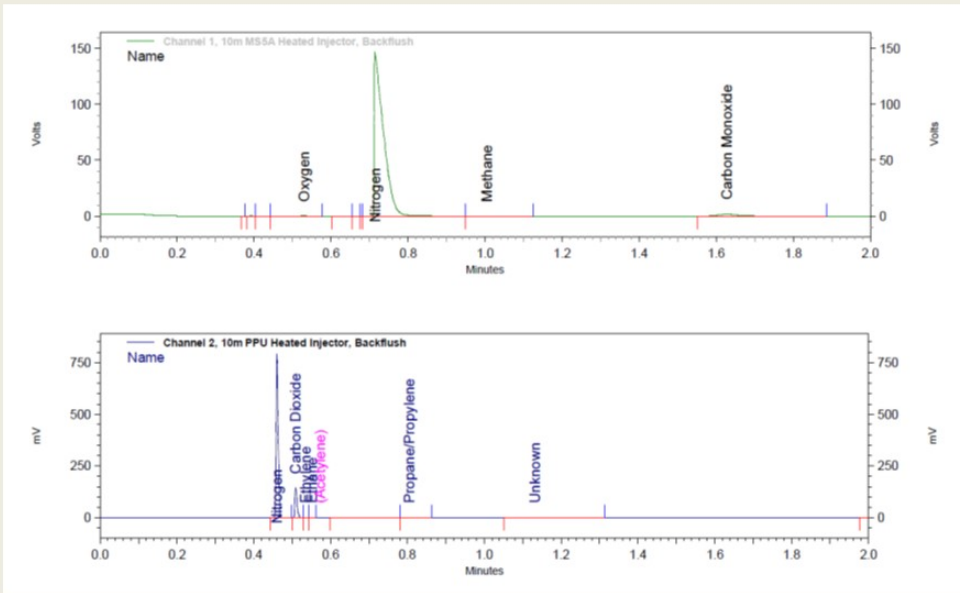
[2] E.D. Tolmachoff et al., *Proc. Western States Section of the Combustion Institute Fall Meeting*, 2015.





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μGC Data



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μGC Data



**Channel 1, 10m
MSSA Heated
Injector, Backflush
Results**

Pk #	Name	Retention Time	Area	Concentration
4	Oxygen	0.529	17290	0.000
8	Nitrogen	0.714	24113046	732136.072
9	Methane	1.004	21340	905.679
10	Carbon Monoxide	1.628	600648	20594.298
Totals			24752324	753635.999

**Channel 2, 10m
PPU Heated
Injector, Backflush
Results**

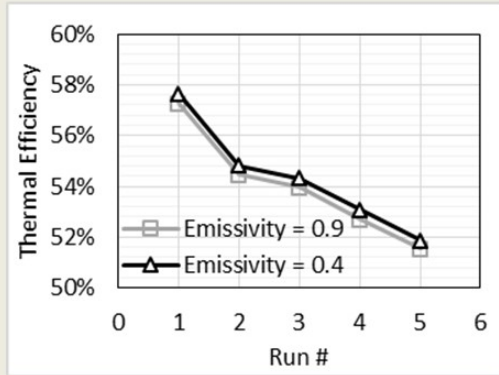
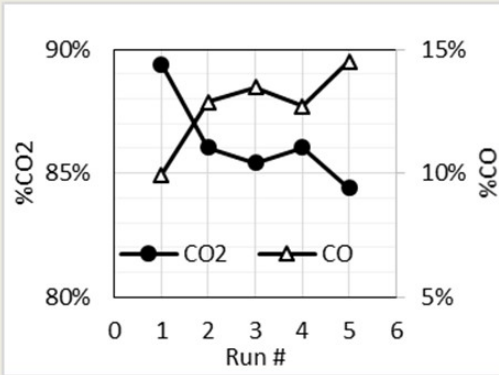
Pk #	Name	Retention Time	Area	Concentration
1	Nitrogen	0.460	20100567	758348.771
2	Carbon Dioxide	0.509	5789016	147104.778
3	Ethylene	0.535	7536	207.323
4	Ethane	0.552	11766	289.732
	Acetylene			0.000 BDL
6	Propane/Propylene	0.805	8151	87.004
7	Unknown	1.131	178882	0.000
Totals			36194938	906037.610



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Effect of Time on Combustion and Thermal Efficiency



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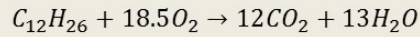
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Equivalence Ratio



$$\phi = \frac{\left(\frac{V_{fuel}}{V_{air}}\right)}{\left(\frac{V_{fuel}}{V_{air}}\right)_{st}}$$

- $\phi = 1$, stoichiometric
- $\phi < 1$, lean mixture
- $\phi > 1$, rich mixture

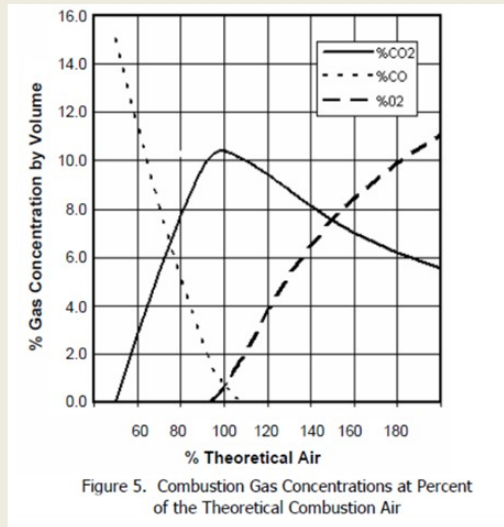


Figure 5. Combustion Gas Concentrations at Percent of the Theoretical Combustion Air

TSI Incorporated, *Combustion Analysis Basics*

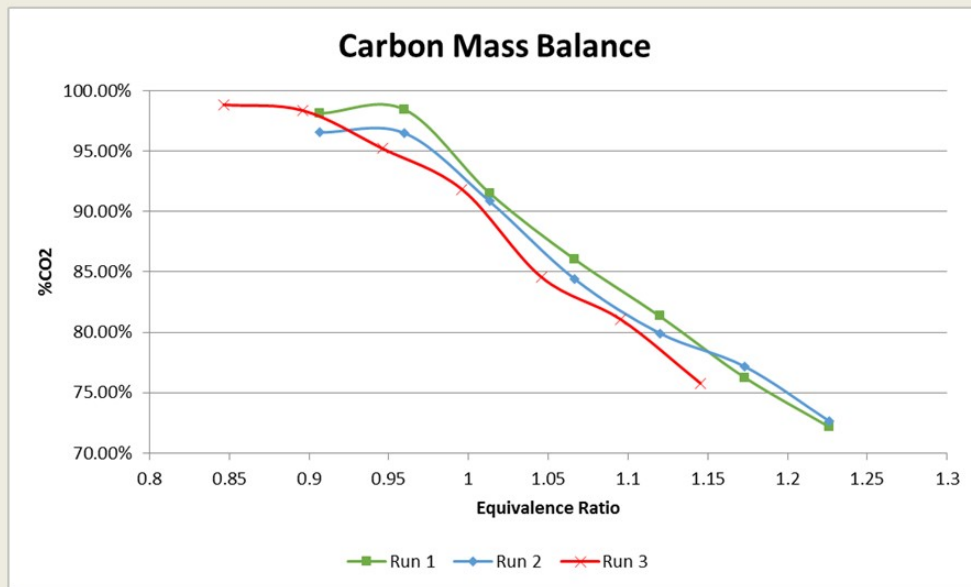
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Summary

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- **Thermal efficiency (radiated heat from desired surfaces)**
 - Over 5 runs, thermal efficiency was 51-58%
 - Demonstrated 20% TPV efficiency [1] combined with 50% combustion efficiency for total efficiency of 10% allowing for energy density of ~700 Wh/kg, 2.1 kg for 72 h, 20 W mission
- **Combustion efficiency**
 - Carbon balance suggests that combustion is nearly complete
- **Heat lost to exhaust**
 - ~3.5% energy lost is due to high-temperature exhaust
- **Radiated heat from undesired surfaces**
 - >15% energy lost is due to radiated heat from undesired surfaces, which can potentially be reflected back
- **Heat lost to conduction along channels**

[1] Wernsman et al., *IEEE Transactions on Electron Devices*, 51 (2004), pp. 512-515.

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- **Emissivity of the reactor is unknown (with higher emissivity while oxidized, decreases when reduced inside vacuum); the diffuse reflection complicates measurements.**
- **Current reactor has a bulge in it due to being heated and high pressure inside the reactor and low pressure outside; earlier modeling done is now inaccurate.**
- **New reactors coming in are to be reinforced.**
- **Experiment with complex fuels rather than simple fuels.**
- **Determine improved methods of depositing catalyst; transition to other catalysts for better resistance to fouling from sulfur.**

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Bill Allmon
John Little



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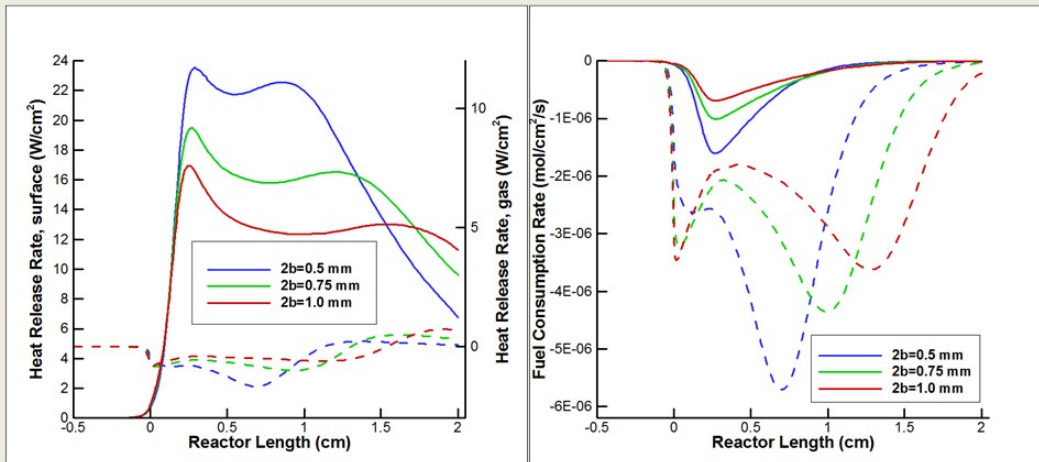


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Selected Results: Effect of Gap Height



Tolmachoff et al., *Combustion and Flame*, 162 (2015), pp. 3674-3680.



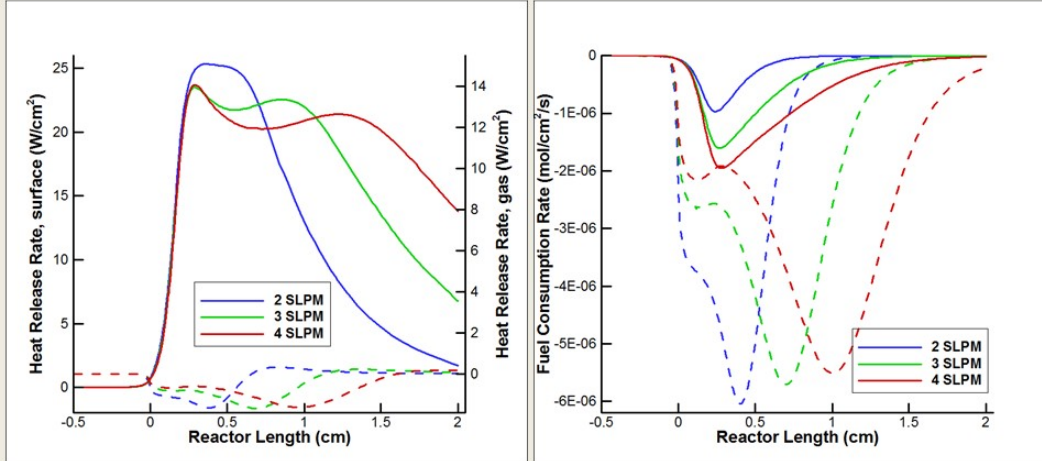
$\dot{V} = 3$ SLPM (156 W), $T_{wall} = 1300$ K
surface (solid lines) gas phase (dashed lines)

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Tolmachoff et al., *Combustion and Flame*, 162 (2015), pp. 3674-3680.



$T_{wall} = 1300\text{ K}$, $2b = 0.5\text{ mm}$
2, 3, 4 SLPM = 104, 156, 208 W, respectively
surface (solid lines) gas phase (dashed lines)

Survivability/Lethality Analysis Directorate (SLAD)

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Visualizing Ferret Brain Neural Pathways to Understand Mechanisms of Blast Brain Injury

Skylar Bodt, CQL Intern

Mentors: Autumn Kulaga & Karin Rafaels, ARL-SLAD

RDRL-SLB-W July 28th, 2016

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Biography

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Fallston High School (2015)

- US Congressional Art Competition
- GEMS at ARL 2012 & 2013



University of Maryland, College Park (2019)

- Major: Cell Biology and Molecular Genetics
- Activities: Beta Psi Omega Professional Biology Fraternity, UMCP Scholar, Quality Enhancement Systems and Teams (QUEST) Honors Program

Future Career Aspirations

- Graduate degree in Medical Illustration
- Continue research as a biomedical illustrator



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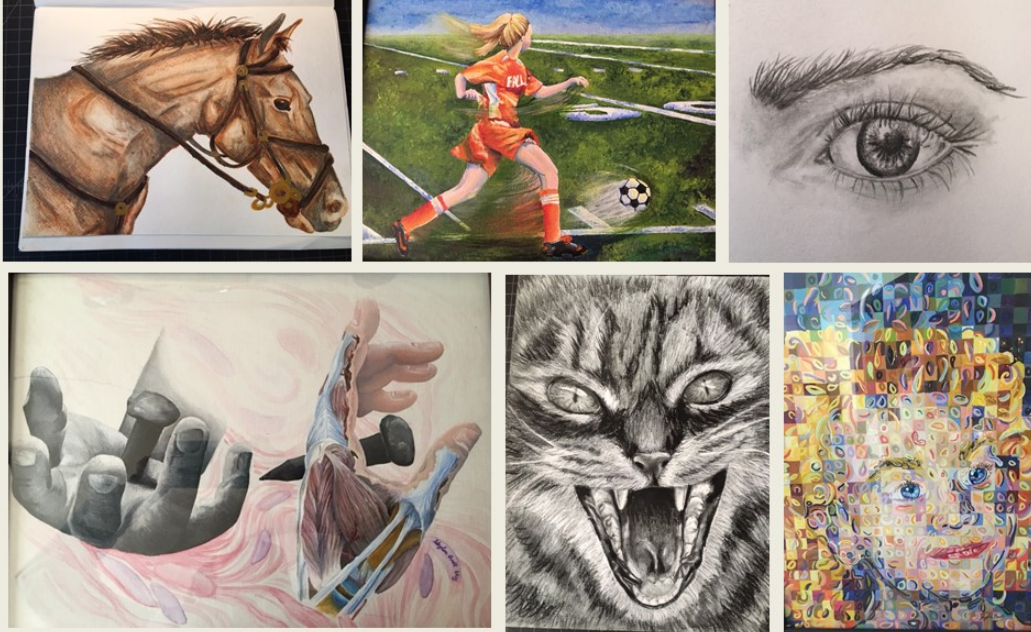
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Additional Artwork

ARL



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Project Goal

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GOAL: Further TBI research through visual reconstruction of neuroanatomy

Objectives:

1. Hand render general images of a ferret brain in ventral, lateral, and dorsal views, clearly identifying regions of the brain. Modify iteratively using Adobe Photoshop and Illustrator.
2. Within these images, locate the position of whole cerebrum sections taken from a ferret brain and stained with *B*-amyloid precursor protein (*B*-APP) or a neurofilament stain (NF), both intended to show axonal damage.
3. Illustrate neural pathways based on the 2D stain images.

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Background: Importance of TBI



Current threats, such as Improvised Explosive Devices (IEDs), make Soldier exposure to blast a continuing concern.



Advances in soldier protective equipment have increased soldier survival rate, but created an increase in nonlethal Traumatic Brain Injury (TBI).

This survival rate increase brings into focus nonlethal TBI, and a need to understand the mechanism of blast injury to the head and neck region (1).

Studying soldier TBI risk due to blast effects is vital for both the treatment of injury and development of protective equipment (1).



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Background: The Ferret Brain



- **Why is it Important?**
 - The ferret brain is important in research because it helps bridge the gap between rat and human brain research.
 - It has more similar surface area to a human but maintains the size of a small rodent brain. (1)
- **What are the challenges?**
 - There is little research available on the ferret brain, so there are gaps in knowledge.
 - Hardly any visualizations have been created, so as a result, known information is difficult for researchers to interpret.
- **Important Previous Research**
 - An experimental program in 2010 used a ferret animal model to explore brain damage after exposure to blast overpressures in a controlled environment. (1)
 - I used this research as the foundation for my own project.

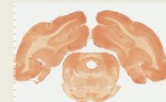
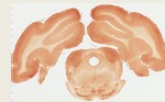
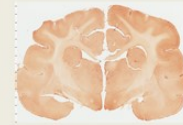
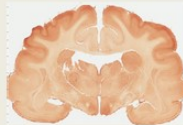




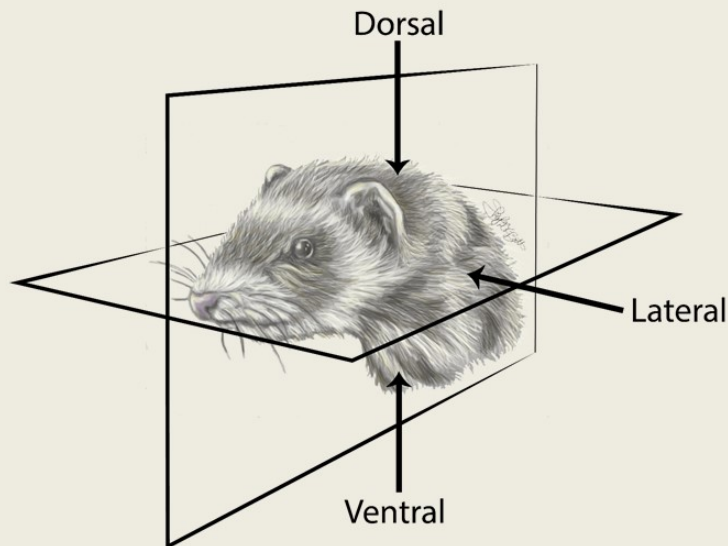
- These are examples of ferret brain slices used in the 2010 experiment studying ferret TBI.
- Both the neurofilament (NF) and the B-amyloid precursor protein (B-APP) stain show axon damage in the brain.
- The precise anatomical location for each of the 20 slices I was given was initially unknown.

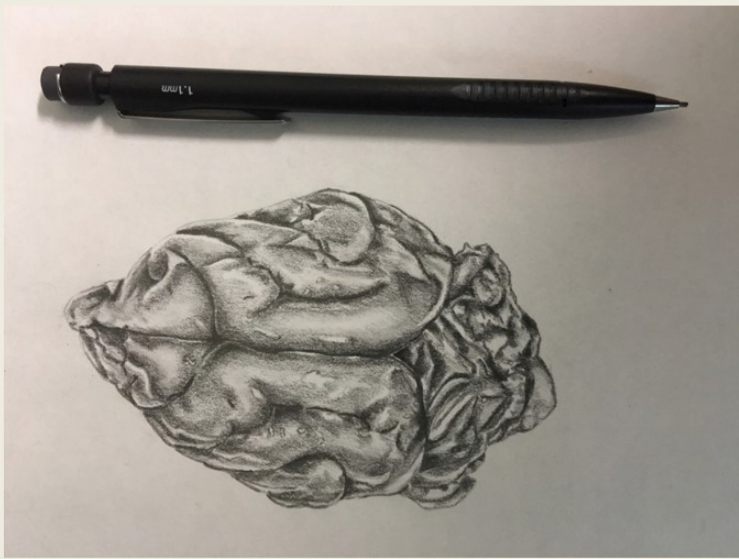
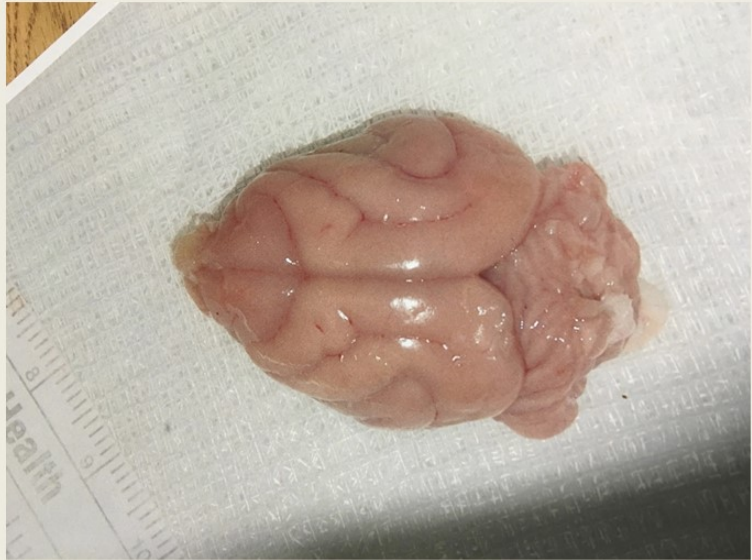
NF

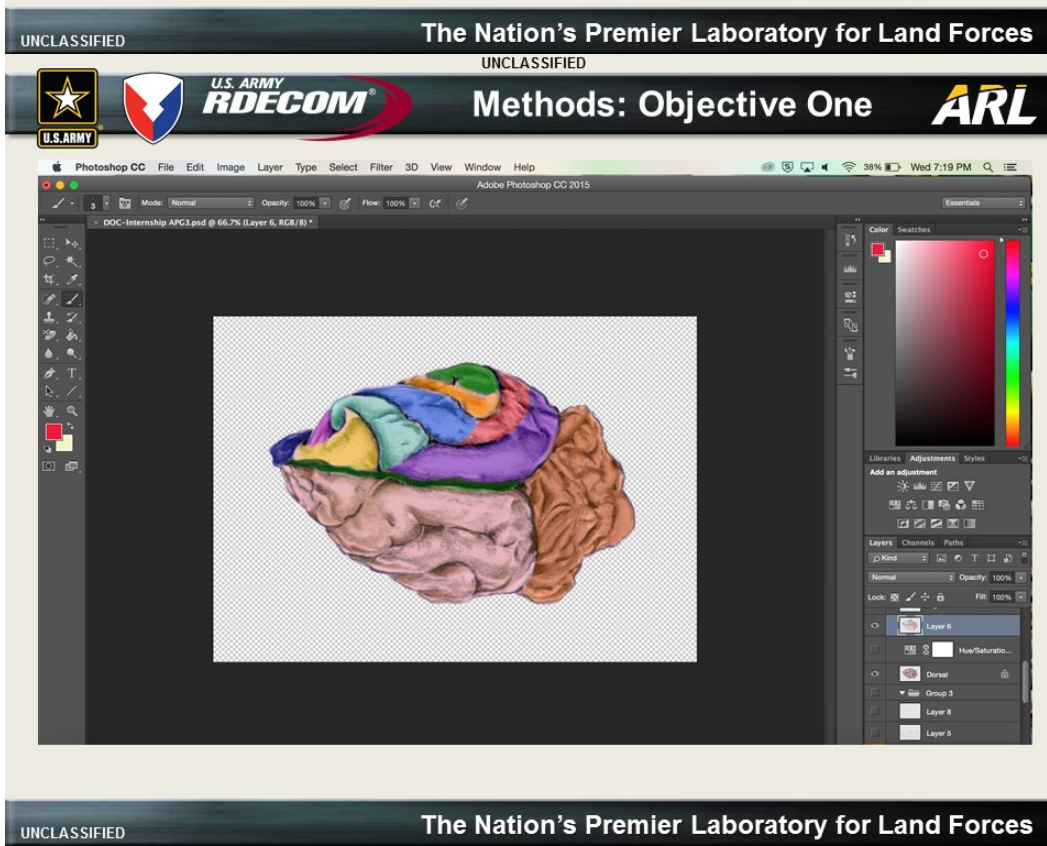
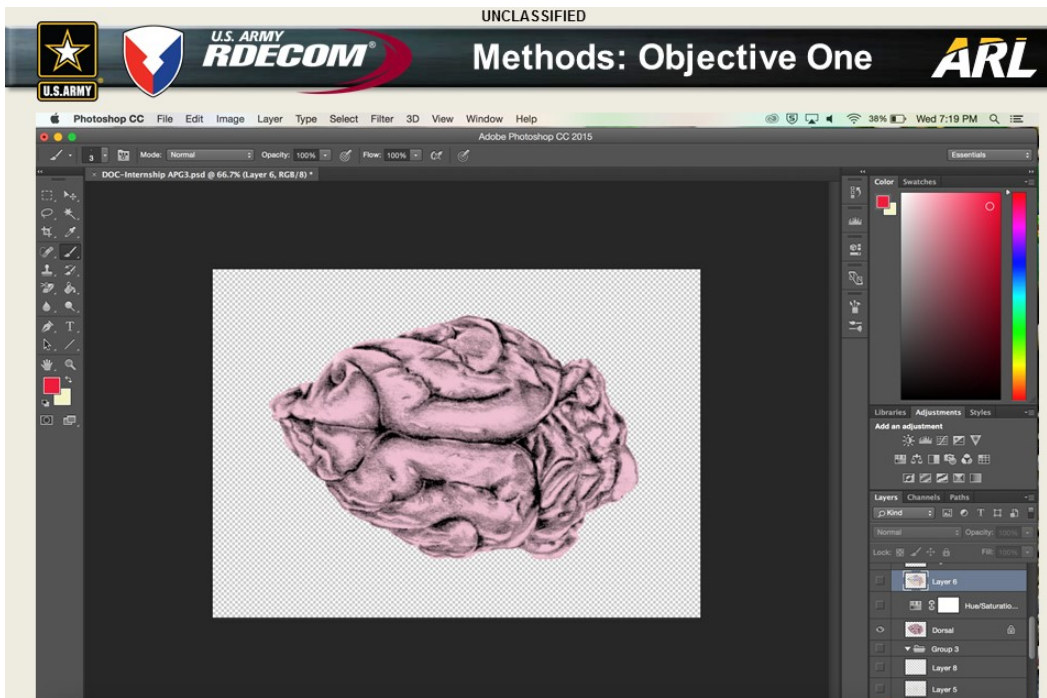
B-APP

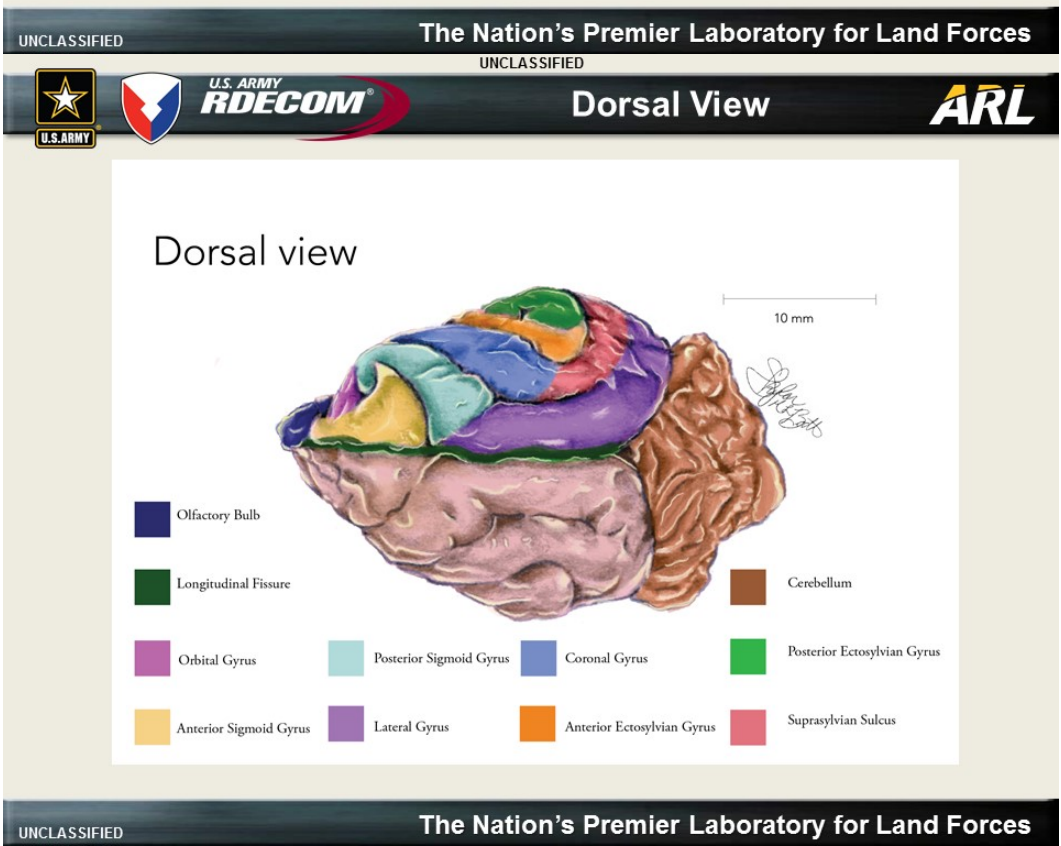
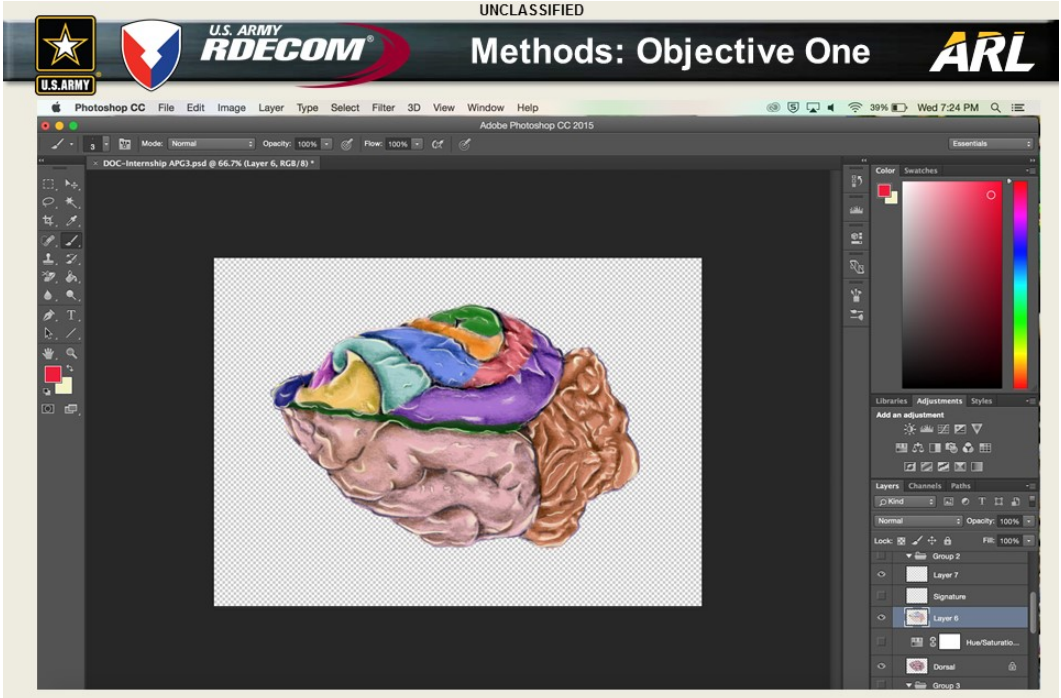


(1)



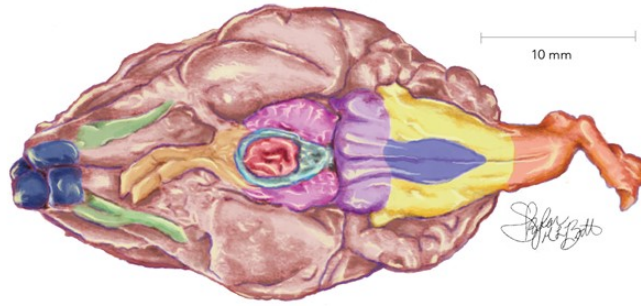








Ventral view



-  Olfactory Bulb
-  Optic Nerve
-  Mamillary Body
-  Pons
-  Medulla
-  Lateral Olfactory Tract
-  Infundibulum
-  Crus Cerebri
-  Pyramid
-  Spinal Cord

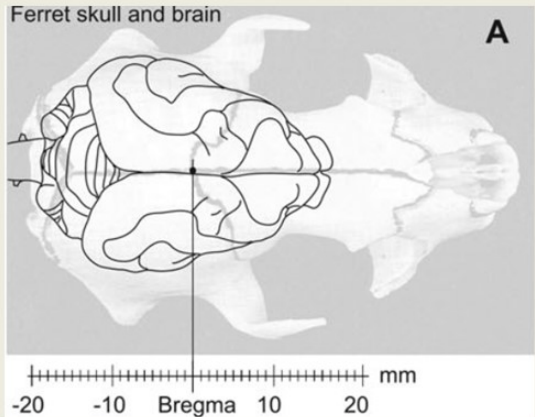


Lateral view

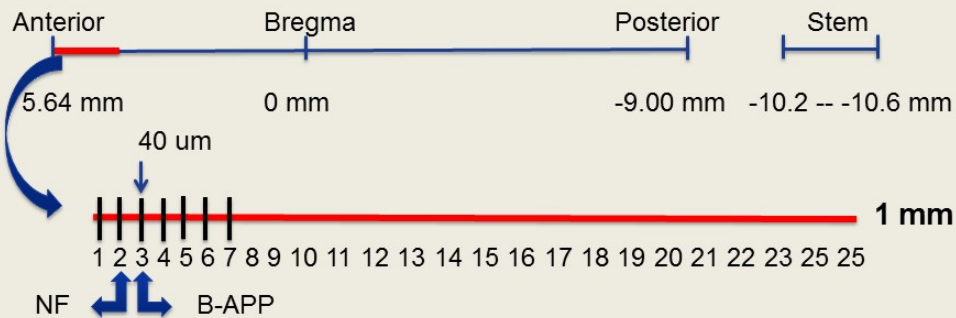


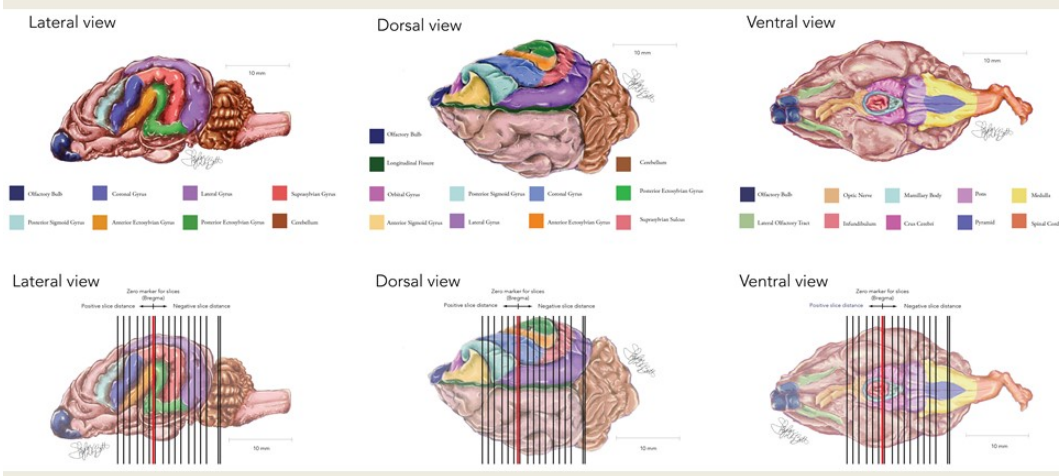
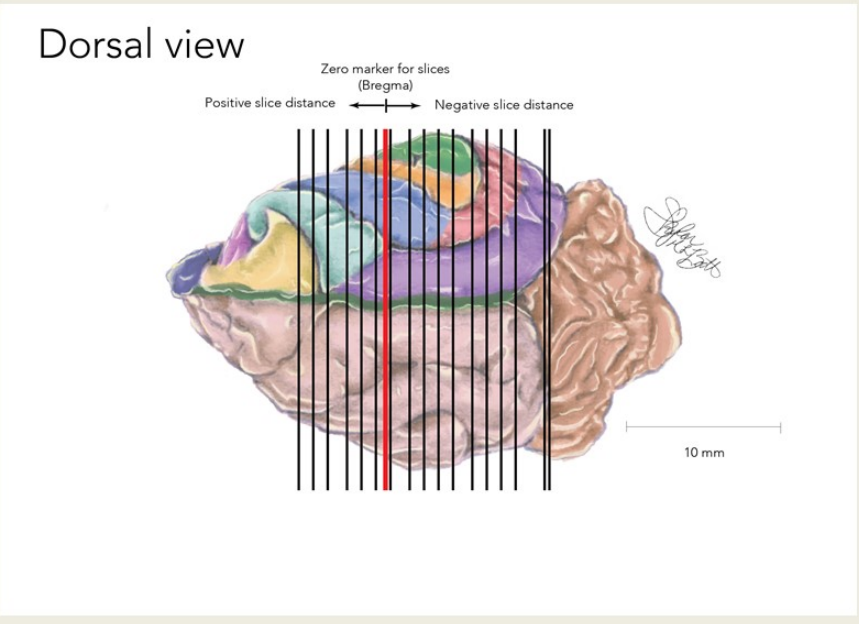
-  Olfactory Bulb
-  Coronal Gyrus
-  Lateral Gyrus
-  Suprasylvian Gyrus
-  Posterior Sigmoid Gyrus
-  Anterior Ectosylvian Gyrus
-  Posterior Ectosylvian Gyrus
-  Cerebellum

- Determined Bregma (0-value) on rendered images (2)
 - Bregma: a location on the front of the skull where plates come together
 - Difficult to determine in ferrets
- Deciphered section placement from description of # mm from Bregma on the ferret brain sample
- Adjusted scale to reflect ~ 3.2 cm ferret brain depicted on 10.4 cm rendered image, (~325% increase)
- Uploaded image into Adobe Illustrator to show slice placement



- 36 sections coronally cut over whole cerebrum, 20 B-App, 16 NF (1)
- Vague description where slices/cuts were made and slide numbering from anterior to posterior. 1 NF & 1-B-APP / mm (1)
- Slide placement estimate by Talairach Stereotactic Coordinates





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Methods: Objective Three

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Notional View of Neural Pathways



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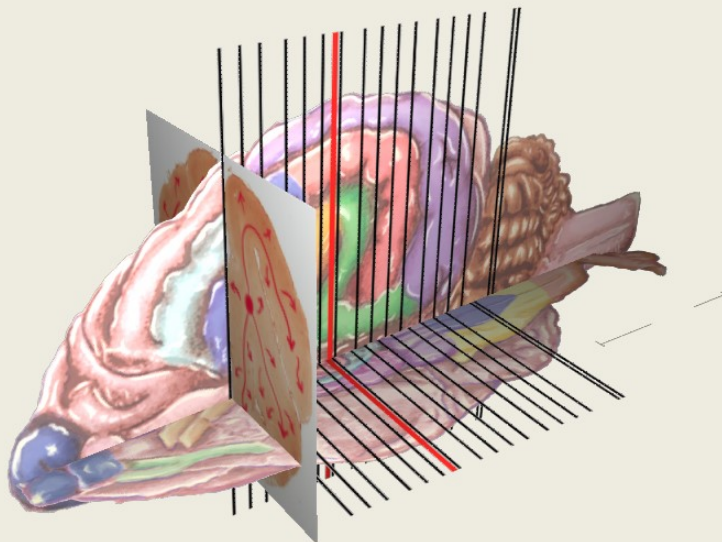
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Methods: Objective Three

ARL



Notional 3D Model

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Summary



- **Understanding TBI is of critical importance to developing better protective equipment and smarter assessment of that equipment.**
- **Visualization of the ferret brain and regions will help researchers identify important structure related to TBI.**
- **Determining slide section locations for NF and B-APP stains allows a visual reference that links the neural pathway damage seen on the sections to a specific region within the brain.**
- **Completed work in depicting connections of neural pathways across sections will move toward a 3D understanding of TBI.**
- **Future work might improve the visualization to allow, for example, “removable” section images from the main image or 3D rendering.**

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Reflections



- **I appreciated this opportunity to be a Medical Illustrator Intern with ARL/SLAD.**
- **The biology, mainly anatomy, required forced me to expand my knowledge.**
- **I now know much more about the regions of the brain and the coordinate system used to locate structures.**
- **I had not previously done anything at this level with Adobe Photoshop and Illustrator; I had only experimented. This summer forced me to become much more proficient in both, but I have much to learn.**
- **I want to thank my mentors Autumn Kulaga and Karin Rafaels for guiding me this summer in Illustration and Biology.**



1. Rafaels, Karin A., "Blast Brain Injury Risk." Diss. University of Virginia, 2010. Print.
2. Cortex, Cerebral, and Doi:10.1093/cercor/bhp164. *Circuit-based Localization of Ferret Prefrontal Cortex* Alvaro Duque and David A. McCormick (n.d.): n. pag. Web.
3. Lawes, I.N.C. and Andrews, P.L.R. "The Neuroanatomy of the Ferret Brain." *Biology and diseases of the ferret*. Ed. James G. Fox. Baltimore: Williams & Wilkins, 1998. 66-99. Print.
4. "Where Soldiers Come From." PBS Premier, 10 Nov. 2011. Web. 25 July 2016.
<http://www.pbs.org/pov/wheresoldierscomefrom/traumatic-brain-injury/>
5. "Result Filters." *National Center for Biotechnology Information*. U.S. National Library of Medicine, n.d. Web. 26 July 2016.



B-amyloid:

- Beta amyloid is a protein fragment detached from an amyloid precursor protein (APP).
- Increased B-APP expression is associated with brain injury (6).

Neurofilament:

- Neurofilaments are important elements in the cytoplasm that supports the cytoplasm in the axon.
- Staining may give insight to axonal damage in the brain (6).

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Vehicle Technology Directorate (VTD)

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Early-Stage Damage in CFRP using Active Thermography

Student: Micheal Wallace

Mentor: Dr. Mulugeta Haile



- Motivation
- Theory
- Experimental Setup
- Results and Discussion
- Summary
- Future work

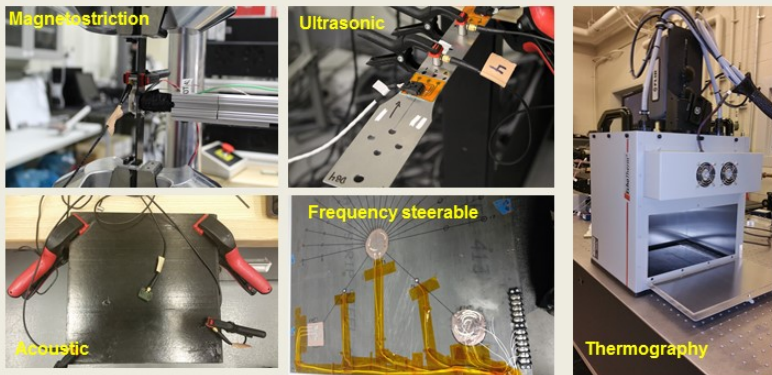


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Objective

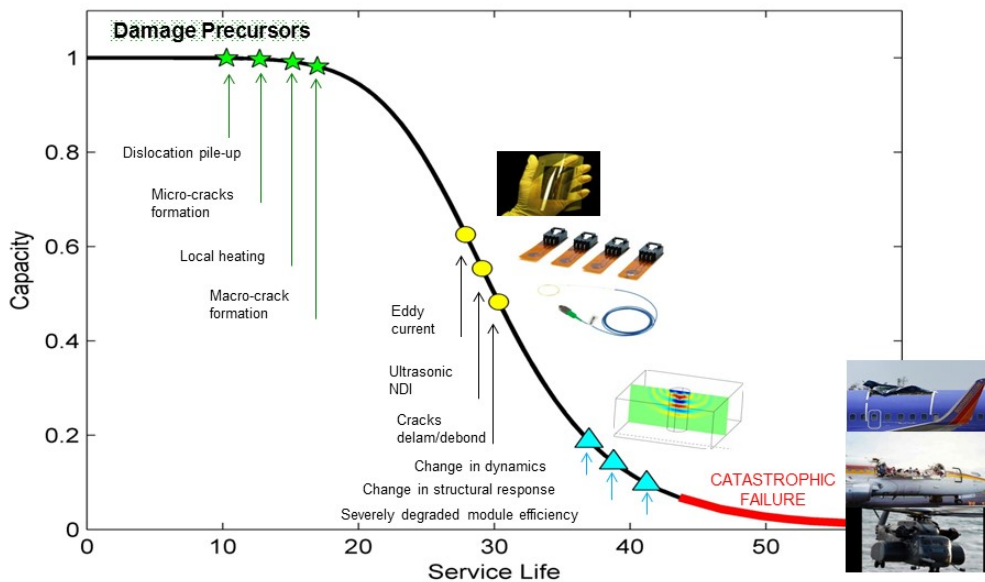


- The overarching objective is to discover in-situ sensing technique for detection of early-stage fatigue damage or “damage precursors” in polymer composites using the materials local thermal properties.



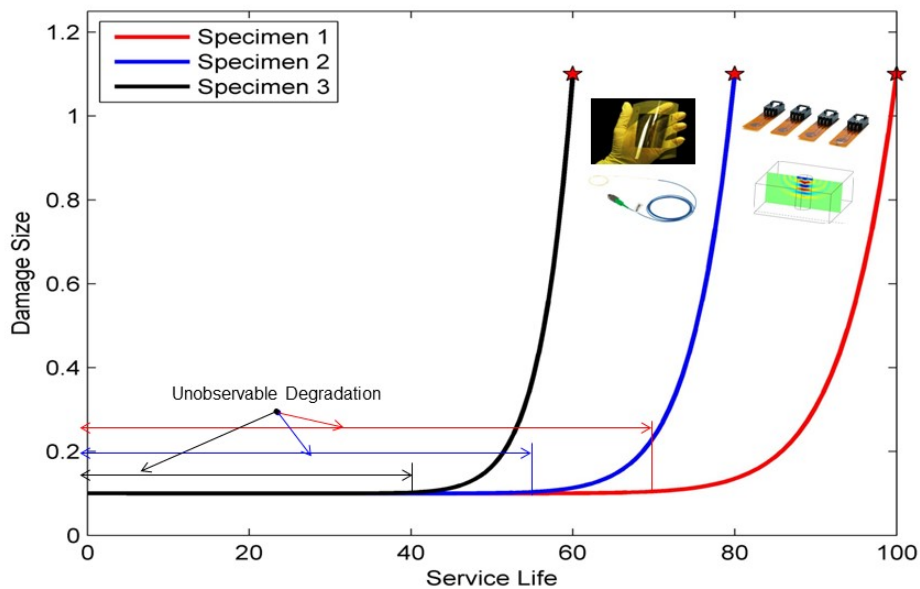
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Capacity vs Life



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Damage Size vs Life



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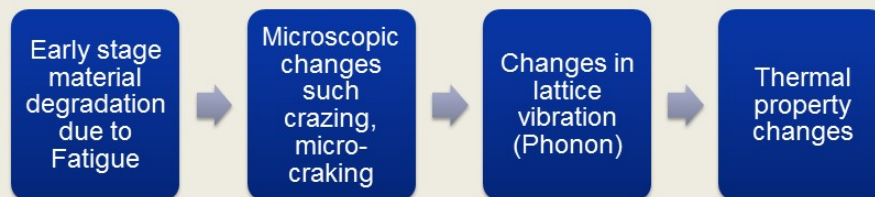
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Theory – Early Damage



- Fatigue damage results in microscopic changes in materials (dislocation, crazing and slip bands).
- Microscopic changes in turn results in changes in the behavior of lattice vibration (or Phonon).
- In nonmetals, heat conductivity is mainly due to phonons.
- All other things constant, changes in materials thermal property, such as conductivity, diffusivity, heat capacity may indicate early stage fatigue damage.



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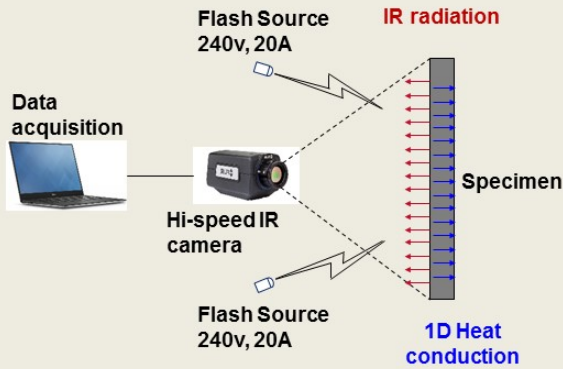
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Theory



Principles of active thermography

Steps:

1. Heat the specimen surface with high intensity flash.
2. Measure surface temperature change ΔT as a function of time, i.e. $\Delta T = f(t)$.
3. Process the temperature time (T-t) data to detect abnormalities.

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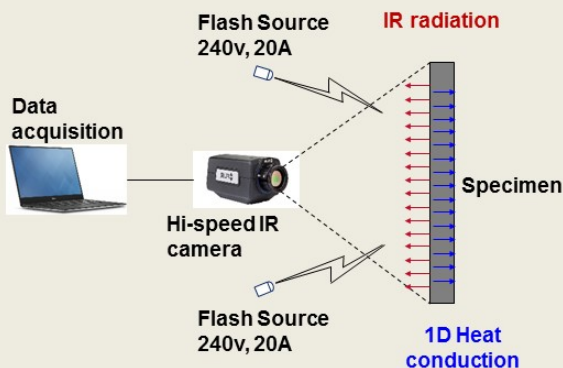
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Theory



Principles of active thermography

Transient Heat Conduction – 1D

- Governing equation (Non-dimensional form)

$$\frac{\partial \theta}{\partial \tau} = \nabla^2 \theta$$

$$\theta(X, 0) = 1, \quad \frac{\partial \theta}{\partial X} = 0 \text{ at } X = 0 \text{ and } \tau > 0$$

$$\frac{\partial \theta}{\partial X} = -Bi \cdot \theta$$

- Solution

$$\theta(X, \tau)_{wall} = A_1 e^{-\lambda_1^2 \tau} \cos\left(\frac{\lambda_1 X}{L}\right), \quad \tau > 0.2$$

- Where

$$\theta(X, \tau)_{wall} = \frac{T(X, \tau) - T_\infty}{T_i - T_\infty} \quad \text{Dimensionless temperature}$$

$$X = \frac{x}{L} \quad \text{Dimensionless distance}$$

$$Bi = \lambda_1 = \frac{hL}{k} \quad \text{Dimensionless heat transfer coefficient, Biot Number}$$

$$\tau = \frac{\alpha t}{L^2} \quad \text{Dimensionless time, Fourier Number}$$

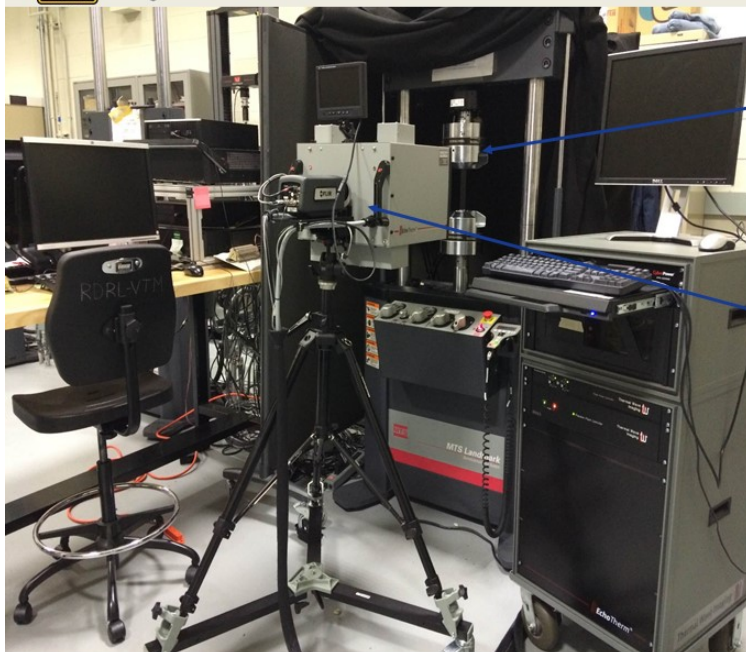
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Experimental Set-Up



MTS with Specimen

IR Camera with EcoTherm Hood

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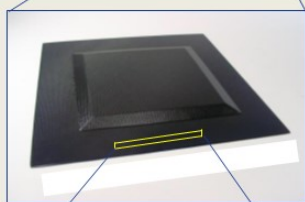


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Test Specimen



Army Platform

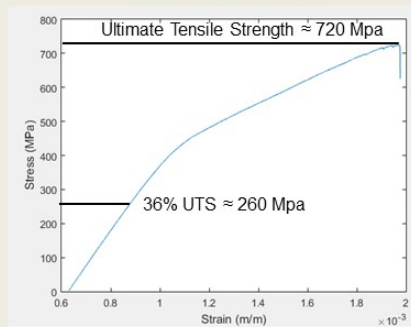


Principal component - Fatigue sensitive panel



Representative element ±45 Multilayer CFRP

Constant spectrum load

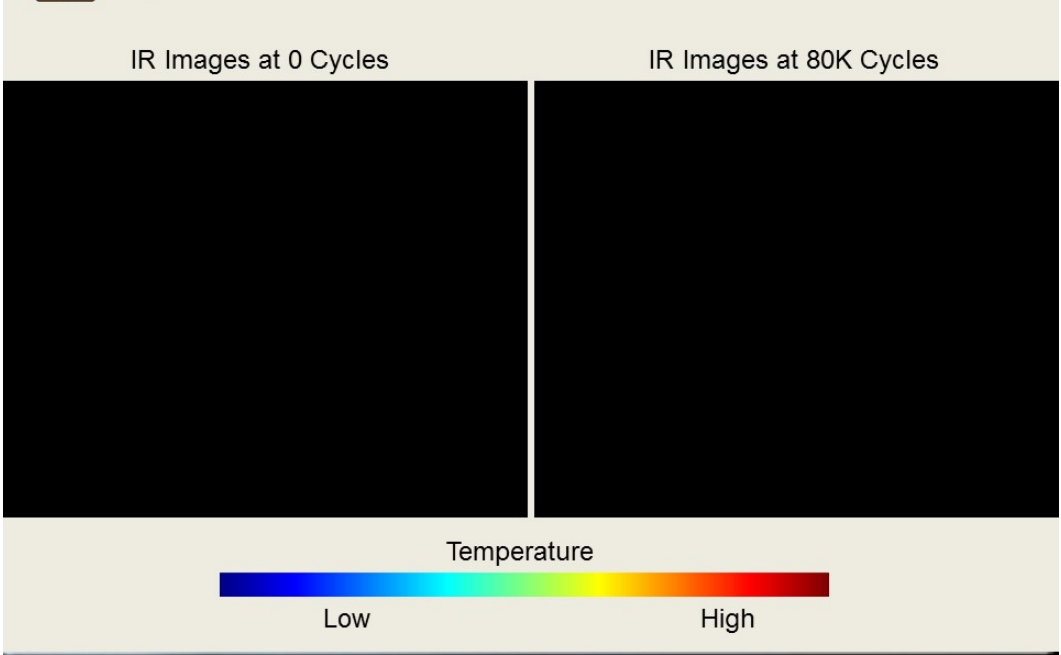
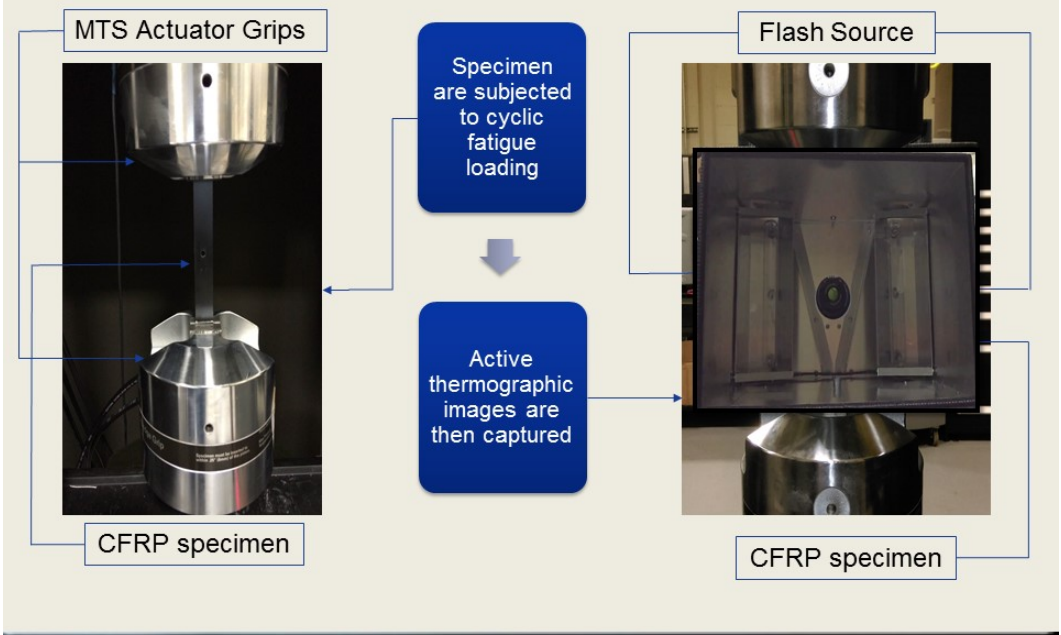


Experimental Parameters

	Representative element
Geometry	W= 25mm, t= 3.5mm, A= 86 mm ² , L= 167 mm
Max	P _{max} = 22.2 kN, σ_{max} = 260 Mpa
Min	P _{min} = 2.2 kN, σ_{min} = 26.0 Mpa
R-ratio	0.1
Spectrum	Uniform

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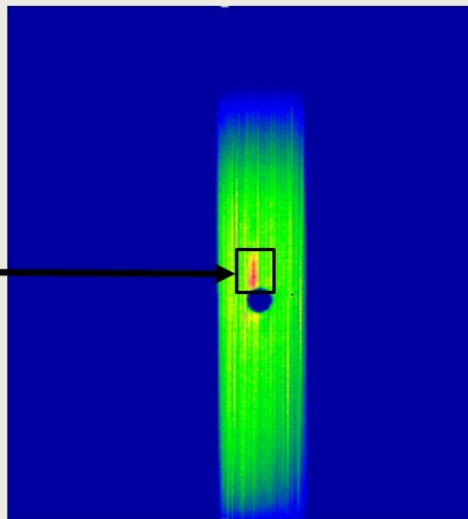


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Infrared Image



Area of Interest



Temperature



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Results



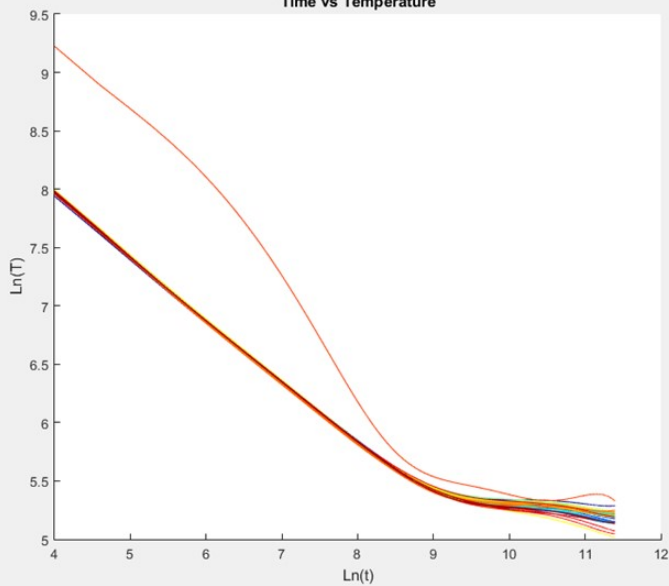
Cycles

Low

High

- 0 Cycles
- 100 Cycles
- 200 Cycles
- 300 Cycles
- 400 Cycles
- 500 Cycles
- 750 Cycles
- 1000 Cycles
- 1250 Cycles
- 1500 Cycles
- 2000 Cycles
- 2500 Cycles
- 3000 Cycles
- 3500 Cycles
- 4000 Cycles
- 4500 Cycles
- 5000 Cycles
- 6000 Cycles
- 7000 Cycles
- 8000 Cycles
- 9000 Cycles
- 10000 Cycles
- 12500 Cycles
- 15000 Cycles
- 17500 Cycles
- 20000 Cycles
- 25000 Cycles
- 30000 Cycles
- 35000 Cycles
- 40000 Cycles
- 45000 Cycles
- 50000 Cycles
- 60000 Cycles
- 70000 Cycles
- 80000 Cycles

Time vs Temperature

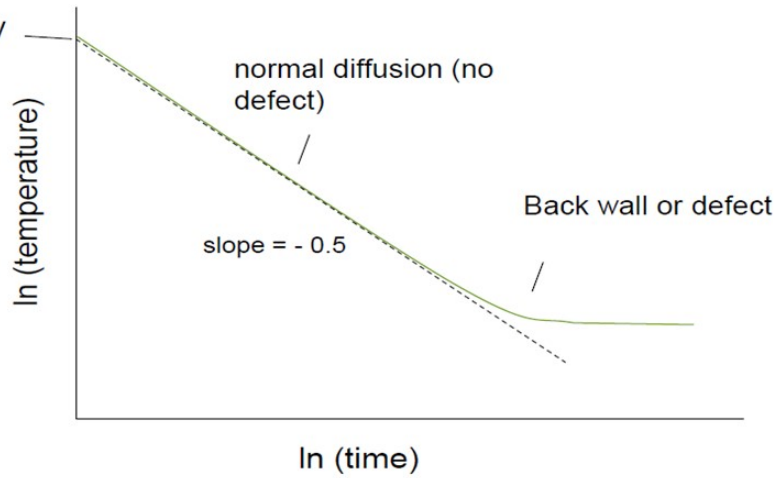


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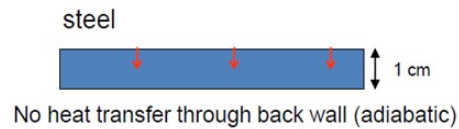
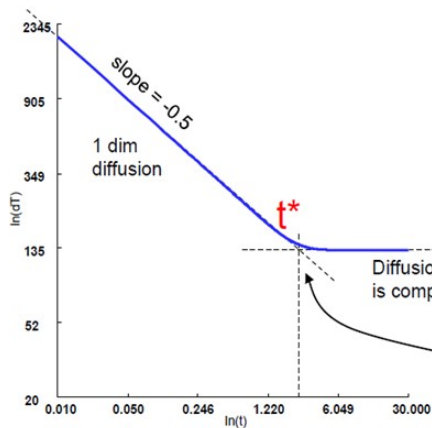
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Interpreting the Log Plot

y-intercept indicates the amount of energy absorbed.



Simple Interface: Adiabatic Boundary



The time t^* characterizes the disruption of the diffusion process by an internal interface.

In the adiabatic case, t^* is the intersection of the straight lines.

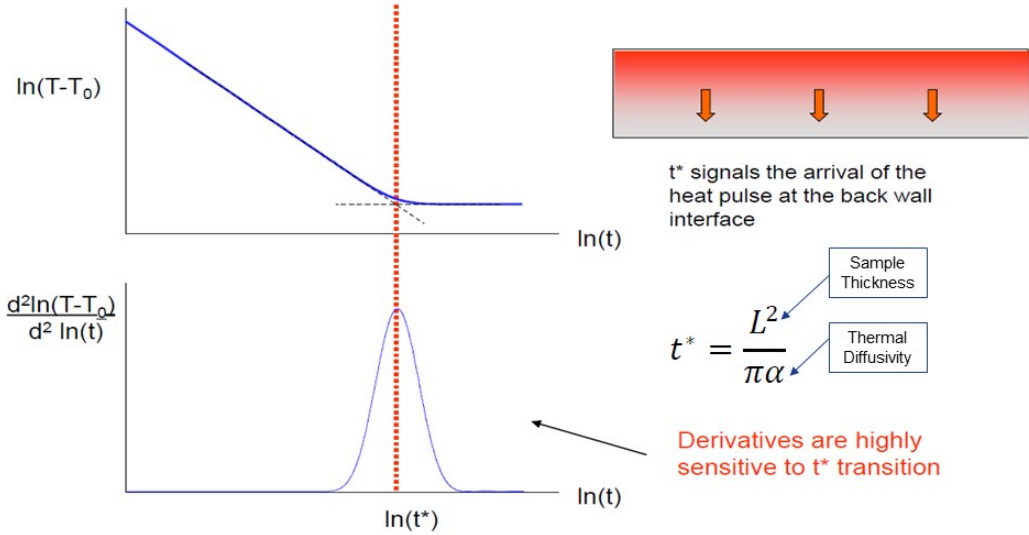


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Results

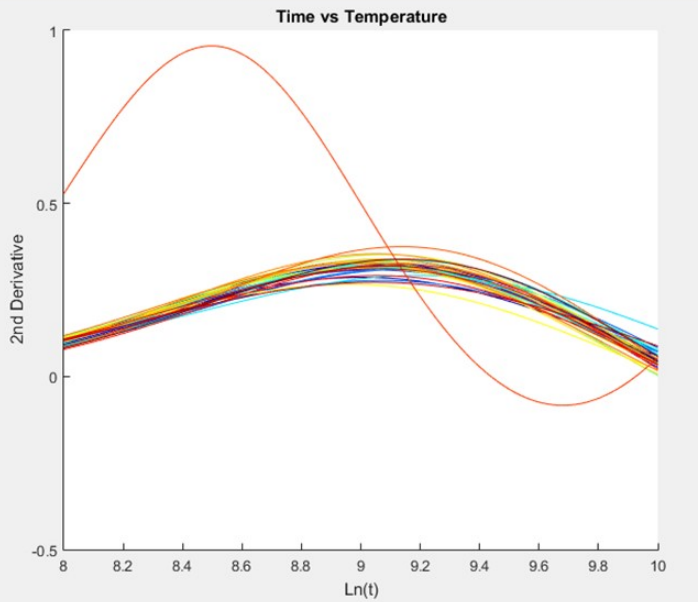
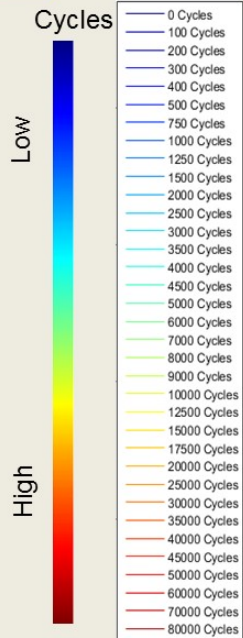


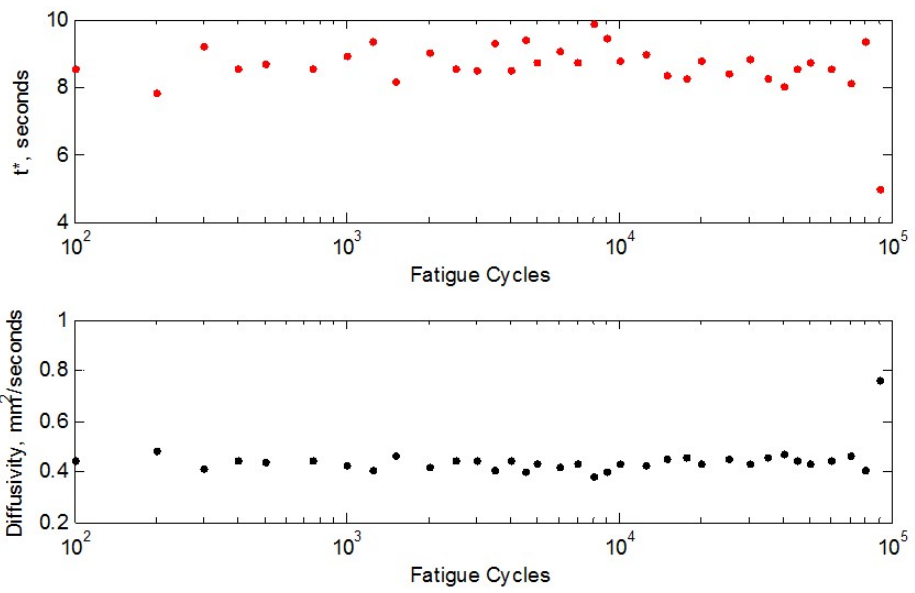
Second Derivative: A Sensitive Indicator of t*



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Results





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QUESTIONS?



Micheal Wallace
UG Intern: Alabama A&M
U.S. Army Research Laboratory (ARL)
Vehicle Technology Directorate (VTD)
Mechanics Division
Aberdeen Proving Ground, MD 21005

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Weapons & Materials Research Directorate (WMRD)

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Aerodynamic Optimization of a Supersonic Bending Body Projectile by a Vector Evaluated Genetic Algorithm

Justin Paul

Mentor: Dr. Sidra Silton

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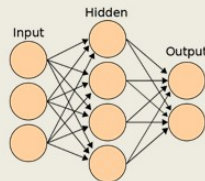
About Me



- I was born and raised in Austin Texas with a strong interest in mathematics and physics.
- I am currently undergraduate senior in Aerospace Engineering at The University of Texas at Austin.



- Interests include rocketry, machine learning, and juggling



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- I. Internship Objectives
- II. Project Description:
 - a) Research purpose
 - b) Projectile studied
 - c) Aerodynamics considered
 - d) Conditions considered
- III. Implementing Optimization
- IV. Simulation Methods Explored
- V. CFD Methodology
- VI. Genetic Algorithms:
 - a) Description
 - b) Advantages and Disadvantages
 - c) Methodology
- VII. Current Results:
 - a) Analysis
 - b) Possible conclusions
- VIII. Path Forward
- IX. Improving Projectile Shape:
 - a) Discuss more realistic projectile shape

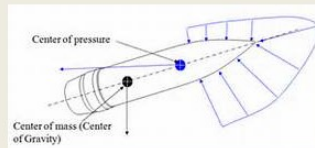


I. Internship Objectives



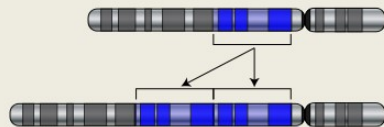
Primary:

- Study ballistic flight dynamics and bending body literature
- Learn to use and experiment with:
 - Missile DATCOM
 - Solidworks Flow Simulation
 - CFD++
 - MIME
- Optimize control parameters for a bending body projectile



Secondary:

- Study evolutionary programming
- Write genetic algorithm to complete optimization (CML-VEGA)

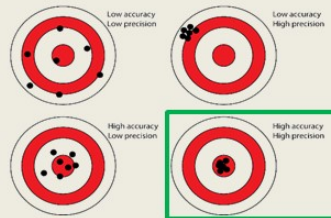




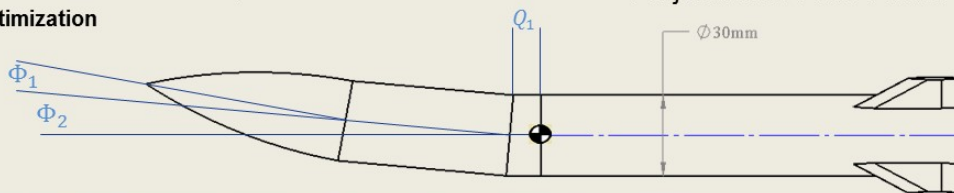
II. Research Purpose



- **Maneuvering flight bodies for small diameter munitions research area**
 - munitions that are both accurate and precise
 - minimize collateral damage
- **Current control authority is limited:**
 - moving control surfaces
 - thrust vectoring
- **Current research done on deflectable projectile structure:**
 - focused on deflecting the nose cone at the base of the nose cone
- **Novel aspects of this investigation:**
 - multiple bends
 - bends located on the body
 - optimization



Projectile: Air Force Finner



-Landers et al. (2003)
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-Shoesmith et al. (2006)
-Youn and Sifton (2016)

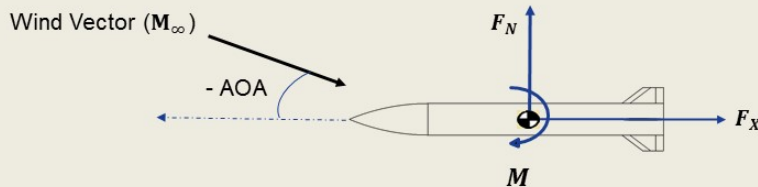
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II. Aerodynamics Considered



- **Pitching Moment Coefficient:** Primary characteristic of control authority

$$C_M = \frac{M}{\frac{1}{2} \gamma p_{\infty} M_{\infty}^2 S D}$$

- **Axial Force Coefficient:** Characteristic of adverse aerodynamics

$$C_X = \frac{F_X}{\frac{1}{2} \gamma p_{\infty} M_{\infty}^2 S}$$

- **Normal Force Coefficient:** Secondary characteristic of control authority

$$C_N = \frac{F_N}{\frac{1}{2} \gamma p_{\infty} M_{\infty}^2 S}$$

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6

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II. Conditions Considered



AOA \equiv Angle between the trajectory vector of the projectile and the freestream vector

M_{∞} \equiv The freestream Mach number

P_{∞} \equiv Ambient pressure in the freestream

T_{∞} \equiv Ambient temperature in the freestream

$$\text{AOA} = \{-8: 1: 8\}^{\circ}$$

$$M_{\infty} = \{2: 1: 4\}$$

$$P_{\infty} = 101325 \text{ kPa}$$

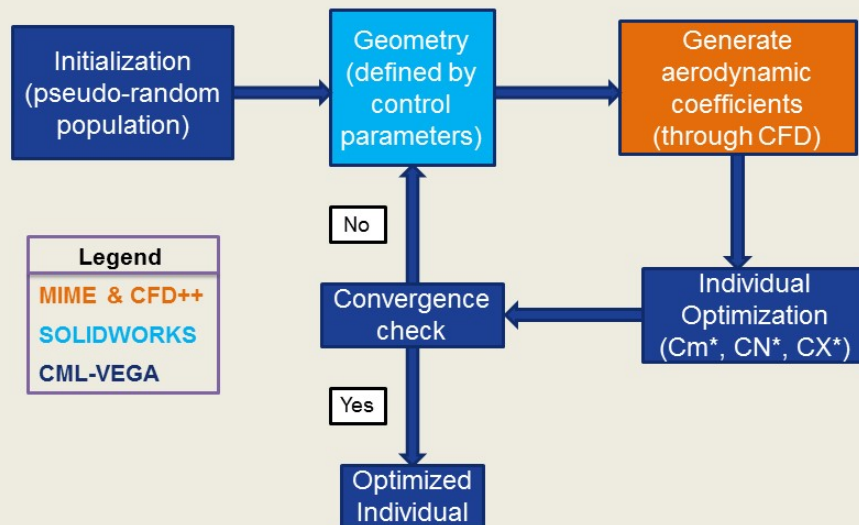
$$T_{\infty} = 293.15 \text{ K}$$

51 Total Cases

AOA (deg)	MACH 2	MACH 3	MACH 4
-8	Case 1	Case 18	Case 35
-7			
-6			
-5			
-4			
-3			
-2			
-1	Case 8	Case 25	Case 43
...



III. Implementing Optimization





IV. Simulation Methods Explored



Aero-prediction code

Missile DATCOM:

- **Fast analysis**
- **Semi-empirical (limited accuracy)**
- **Limited modeling capabilities**

Legend

Advantages

Disadvantages

Computational Fluid Dynamics Solvers

SOLIDWORKS Flow Simulation:

- **Integrated into CAD software**
- **Fast meshing**
- **Limited licensing and resources**
- **Limited to windows systems**

CFD++:

- **More sophisticated solver**
- **Near unlimited licensing and resources**
- **Compatible with UNIX workstations (and therefore HPC)**
- **Requires MIME software for meshing**



V. CFD Methodology



CFD++

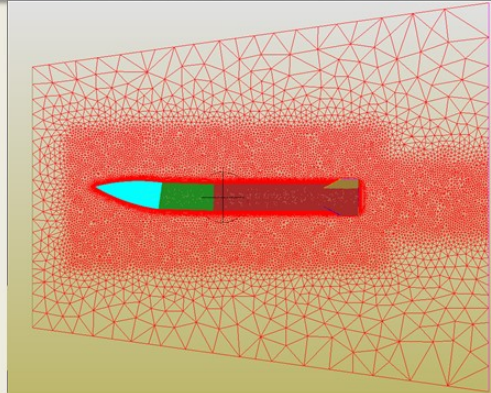
Version 15.1.1 of CFD++:

- **Steady-state and quasi-steady sweep RANS simulations**
- **Realizable $k\epsilon$ turbulence model**
- **Finite volume framework**

MIME

Version 5.1 of MIME:

- **Unstructured tetrahedrals with prism boundary layer**
- **Local refinement on nose cone tip, bends and edges**
- **Curvature refinement across nose cone**
- **Global mesh size typically 9.1 to 9.6 million cells (taking advantage of longitudinal symmetry)**





VI. Genetic Algorithms



Defining Aspects of a Genetic Algorithm:

- **Metaheuristic** (practical solutions)
- **Stochastic** (search and propagation utilize pseudo random number generation techniques)
- **Conditionally Global** (initial population size, crossover probability and mutation rate dependency)

Advantages:

- Robust composition is insensitive to initial condition variation
- Relatively simple to implement on relatively complex systems

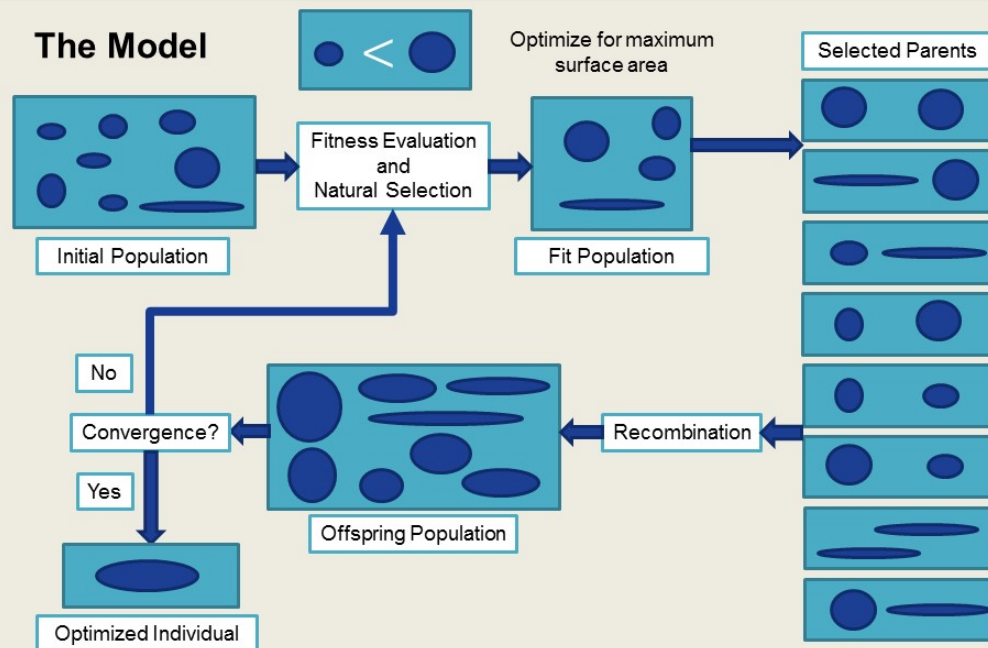
Ex: $\text{size}(Q_1) * \text{size}(\Phi_1) * \text{size}(\Phi_2) = 16 * 16 * 16 = 4096$ configurations

Disadvantages:

- Does not scale well – increasing quantity of control parameters increases the diversity of design space exponentially
- High dimensional, multimodal problems require sophisticated and expensive fitness functions



VI. Genetic Algorithms





VI. The Objective Function



For a given set of aerodynamic coefficients: $min: niche: max$

$$size = \frac{max - min}{niche}$$

$$value\ score = \frac{value}{max} * size$$

$component\ score = priority\ coefficient * value\ score$

$$final\ fitness\ score = \sum_{j=1}^N (component\ score)_j$$

$\langle (1/2)C_M, (1/3)C_X, (1/6)C_N \rangle$

$$fitness\ proportionate\ probability = \frac{(final\ fitness\ score)_i}{maximum\ final\ fitness\ score} = \frac{w_i}{w_{max}}$$

Minimization modification: $value\ score = \frac{min}{value} * size$

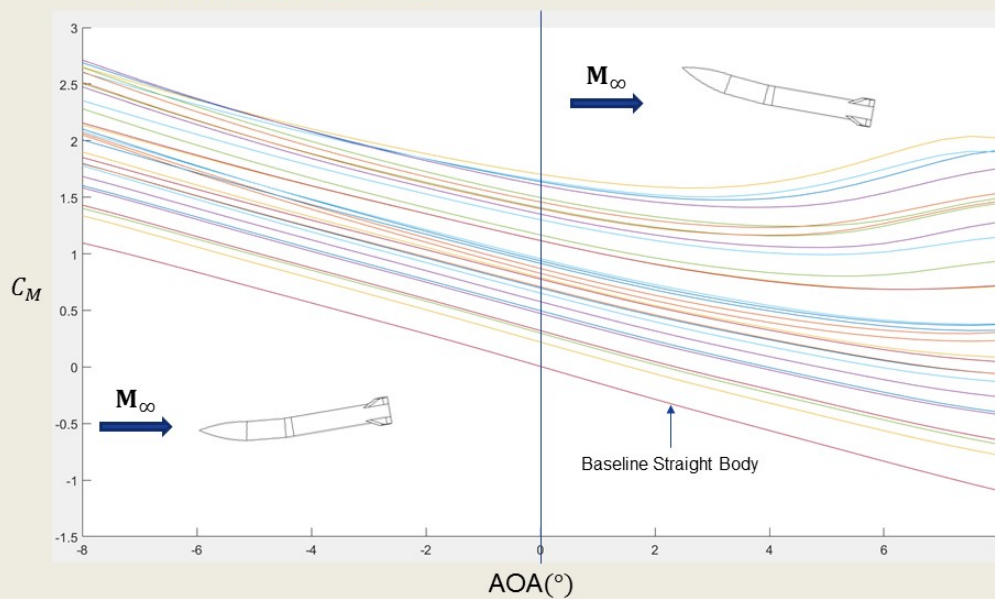
*The complete objective function includes CFD simulation calculations



VII. C_M vs AOA



Pitching Moment Coefficient: Primary characteristic of control authority

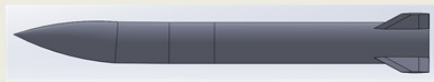


Mach 2, AOA 8°

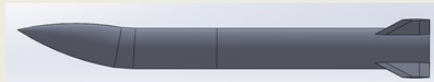
Generation 1



Individual 4



Individual 26



Individual 29

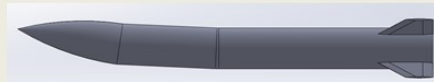
Generation 2



Individual 1



Individual 4



Individual 6

$length(0:0.5:7.5) = length(1.25:4.5:68.75) = 16$ **Mach = 2**

Generation 1

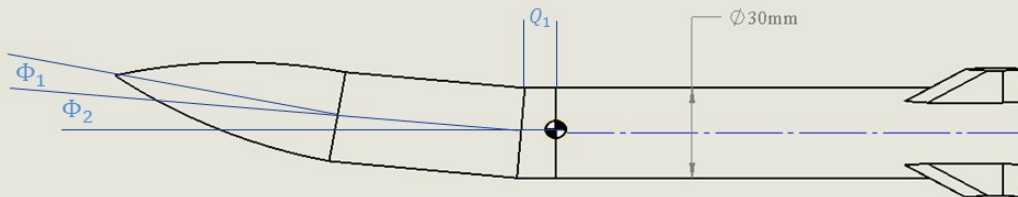
Mean Std. Dev. 4.71

	Q_1	Φ_1	Φ_2
Mean	8.97	8.19	8.10
Std. Dev.	4.71	4.89	4.52

Generation 2

Mean Std. Dev. 3.69 **22% reduced standard deviation**

Angle of Attack	AOA -8°	AOA -7°	AOA -6°	AOA -5°	AOA -4°	AOA -3°	AOA -2°	AOA -1°	AOA 0°	AOA 1°	AOA 2°	AOA 3°	AOA 4°	AOA 5°	AOA 6°	AOA 7°	AOA 8°
Mean Standard Deviation	3.77	3.95	3.85	4.21	2.82	2.99	2.88	2.55	4.63	4.57	4.34	4.54	3.43	2.21	4.13	4.27	3.60





VIII. Path Forward



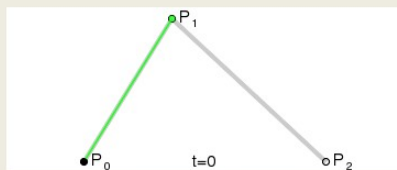
- Algorithm functionality is not completely confirmed – observed increase in performance will verify optimization.
- Central Objective: complete optimization of unique problems (characterized by C_M vs AOA)
Ex: AOA = 8° for Mach = {2:1:4}
- Complete statistical analysis of algorithm convergence to understand why some problems may converge faster than others.
- Look for significant differences between problems with related conditions to derive conclusions.
- Analyze flow field characteristics of optimized individuals to understand increased performance compared to the baseline straight body configuration.



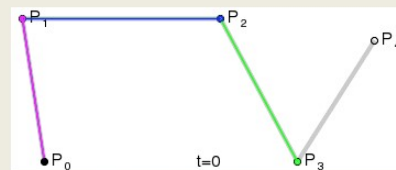
IX. Improving Projectile Shape



Use Bezier control points to create a continuous shape (Li et al. 2016)



Second Order Bezier Curve



Fourth Order Bezier Curve



Acknowledgements



The author would like to thank:

- **Mr. Ilmars Celmins** of the Flight Sciences Branch, WMRD, ARL, for his assistance with SOLIDWORKS
- **Mr. Bryant Nelson** of the Guidance Technology Branch, WMRD, ARL, for his assistance with concept development and GA conceptualization.

This study used significant computational resources provided by the **Department of Defense High Performance Computing Modernization Program** at the Navy DoD Supercomputing Resource Center located at Stennis Space Center, Mississippi.



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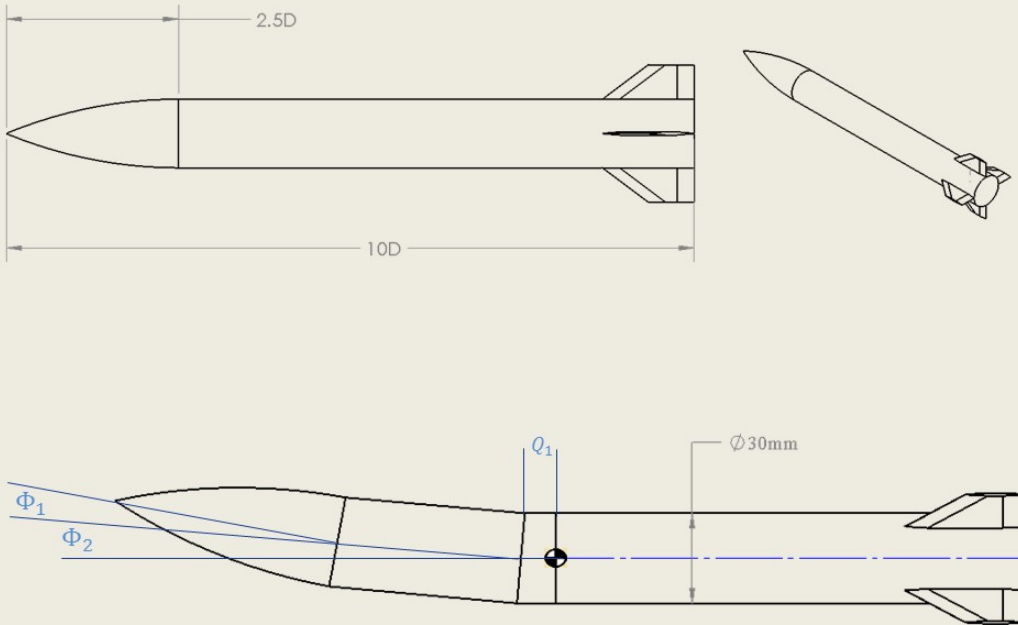
18. <https://Cma.net63.net> , 08/2/2016 - Ballistic Projectile



QUESTIONS?

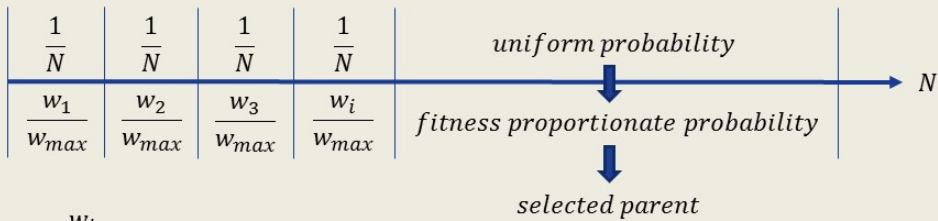


APPENDIX

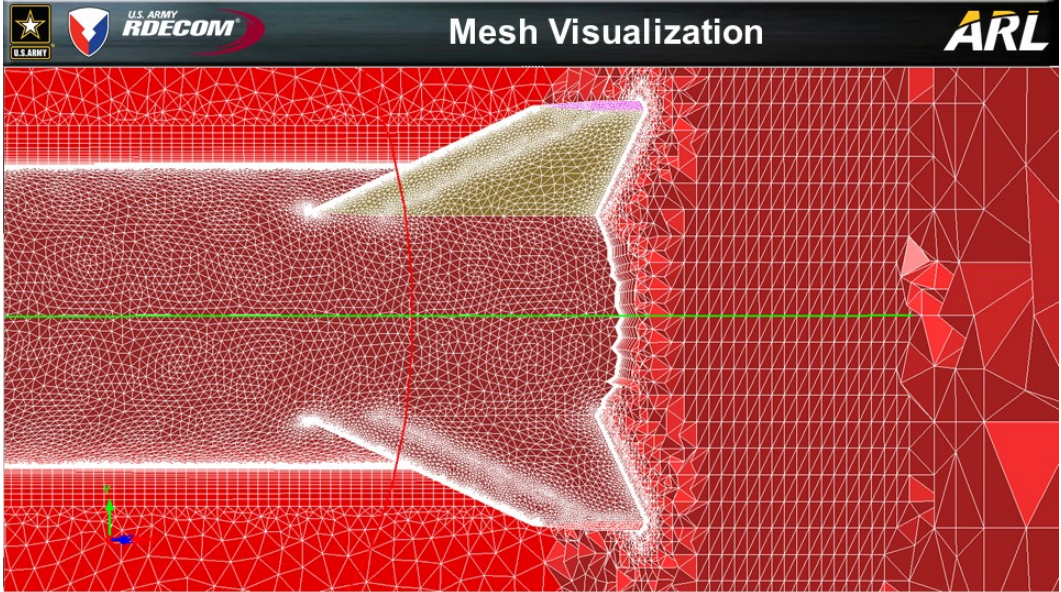


- **Natural Selection:**
 - median population fitness is calculated
 - individuals at or below the median fitness are removed from the population to create the “fit” population

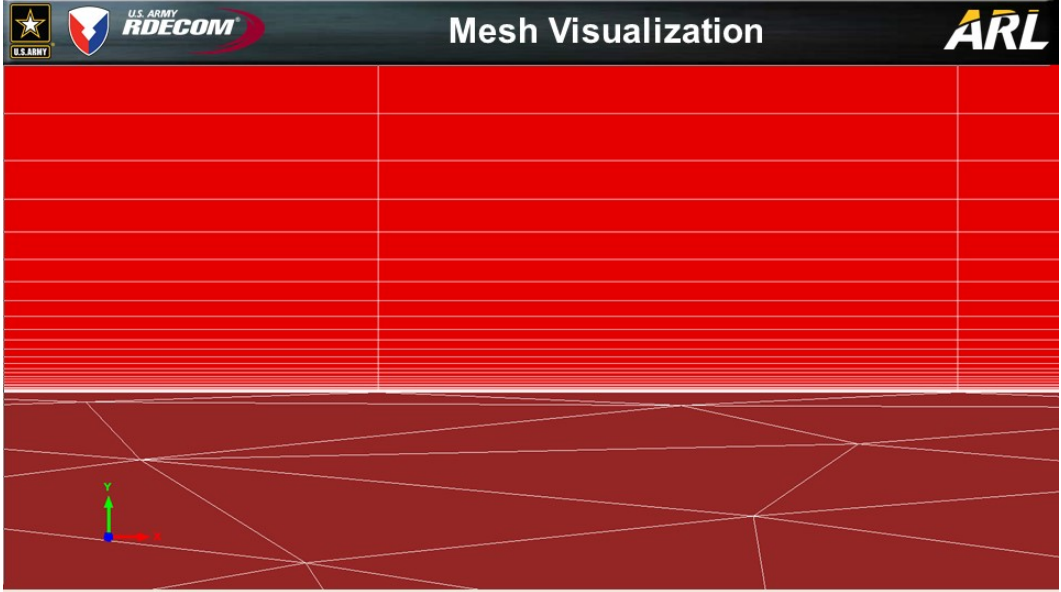
• **Parental Selection:**



if $\frac{w_i}{w_{max}} > x, 0 < x < 1$
 individual i is the selected parent



Three dimensional cut-plane of fin region cells



Boundary Layer Size: 4.2e6



Data Comparison

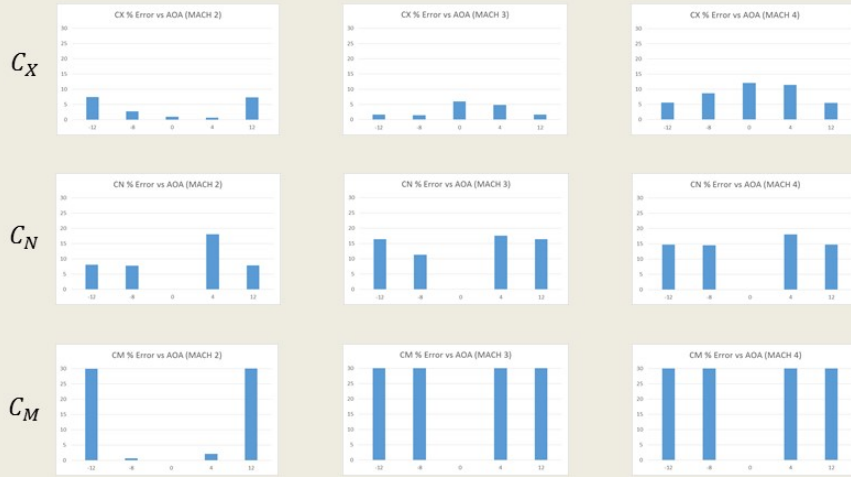


Comparing Missile DATCOM to CFD++

Mach 2

Mach 3

Mach 4



Data Comparison



Comparing SOLIDWORKS Flow Simulation Solver to CFD++

Mach 2

Mach 3

Mach 4



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Comparison and Optimization of Solid-State Joining Techniques for Dissimilar Metals

Miriam Silton

Coatings, Corrosion, and Engineered Polymers Branch (CCEPB)

Mentor: Dr. Robert Jensen

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Contents

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- About me
- Background
- Goals
 - Fabricate and characterize standardized joints
 - Produce baseline performance predictions
- Conclusions and Future Work

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About Me



➤ Education

- Rising junior at University of Maryland, College Park
- Materials Science and Engineering
- University Honors College
- QUEST Honors Program



➤ Experience

- Summer 2015: Adhesives with ARL CCEPB
- 2015-2016 school year: UHMWPE and resin degradation in body armor panels



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Background



➤ Motivation

- Increased maneuverability and fuel efficiency
- Substitute lightweight metals for steel → joints

➤ Challenge

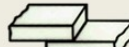
- Optimal joining techniques for all possible situations are unknown
- Tradeoff between weldability and strength
- Galvanic corrosion and fatigue concerns



Butt



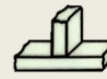
Corner



Lap



Edge

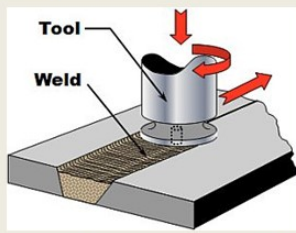


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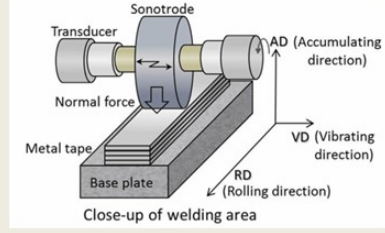
➤ Opportunity

- ARL is home to diverse joining portfolio

Materials Research Campaign: Lightweight Materials



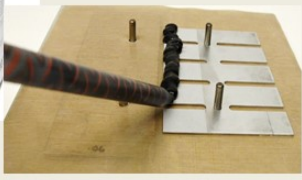
Friction Stir Welding (FSW)



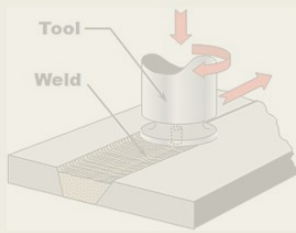
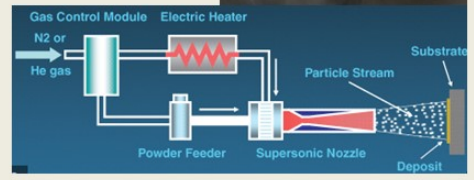
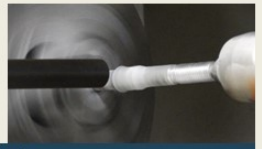
Ultrasonic Additive Manufacturing (UAM)



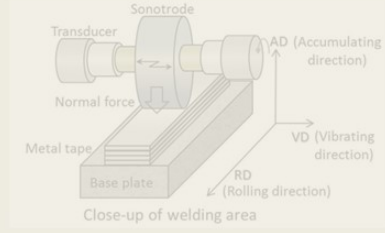
Adhesives



Cold Spray



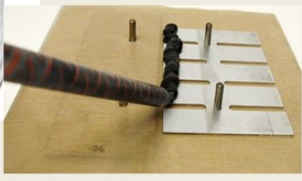
Friction Stir Welding (FSW)



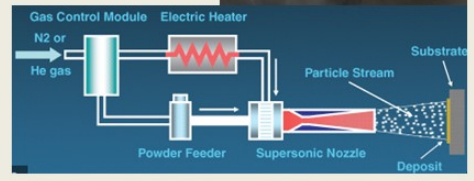
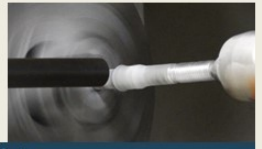
Ultrasonic Additive Manufacturing (UAM)

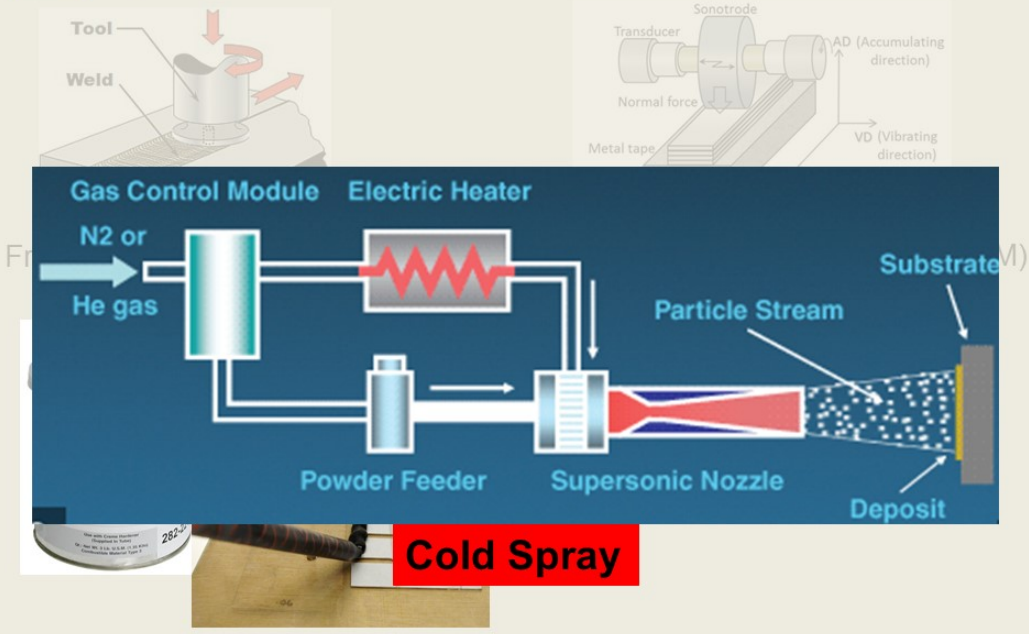


Adhesives



Cold Spray



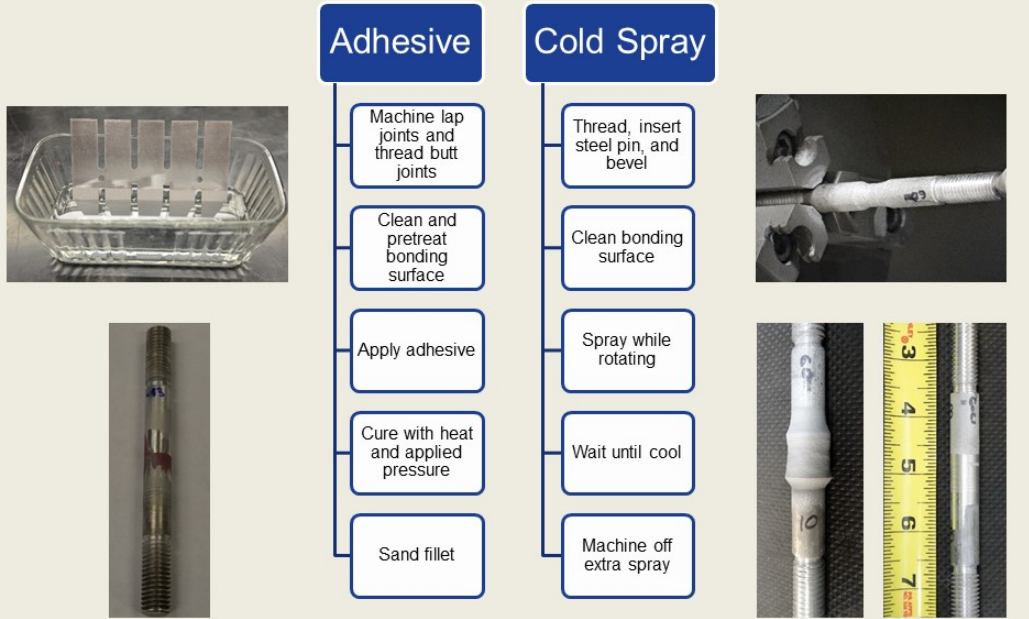




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Joint Fabrication

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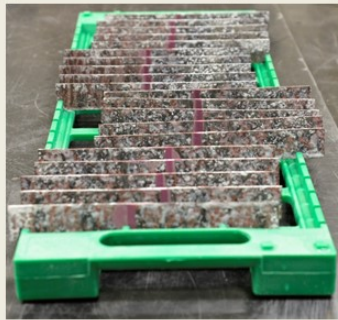


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Characterization

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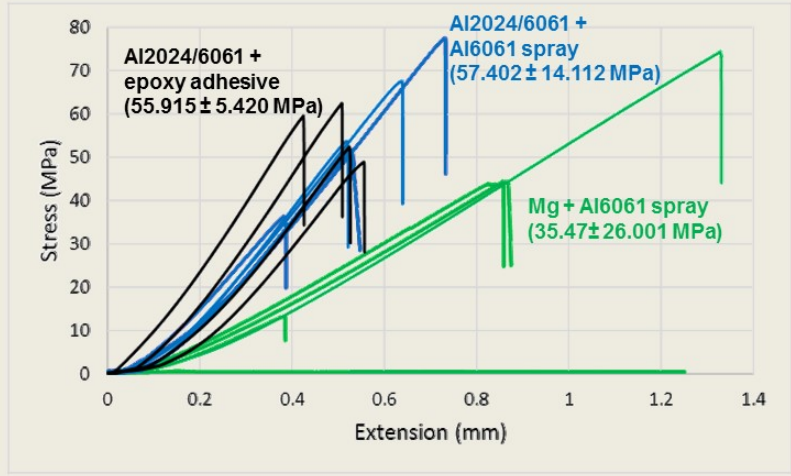
- **Standard tensile testing of butt joints (ISO 6922/ASTM 2095)**
 - **Adhesive: dissimilar Al alloys**
 - **Cold Spray: dissimilar Al and Mg alloys with Al spray**
- **Post-corrosion tensile testing of adhesive lap joints**
 - **30 days in salt fog chamber**
 - **5% NaCl-water solution @ 35°C (ASTM B117)**
- **Cyclic fatigue testing of adhesive lap joints (ASTM D3166)**



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- Cold spray: high potential vs. large standard deviation
- Adhesive: consistent + comparable strength





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Trying something new



➤ Current Literature

- Hybrid joints combining adhesives with UAM and FSW
- Cold spray is new technique with limited research

➤ Hybrid Cold Spray-Adhesive Butt Joint

- High strength of cold spray
- Reliability of adhesive
- Optimal joint for this geometry?
 - Hypothesis: Combination will eliminate crack and reduce stress concentrators at edge.

➤ Considerations

- **Ensure weld heat doesn't degrade adhesive**
 - Degradation temp ~360°C
 - Surface during cold spray application ~60°C

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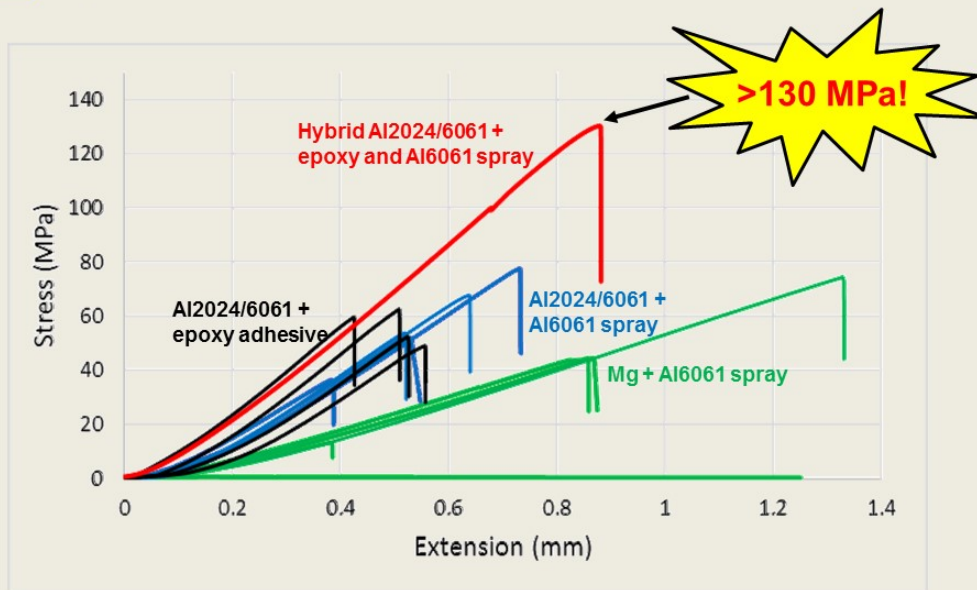
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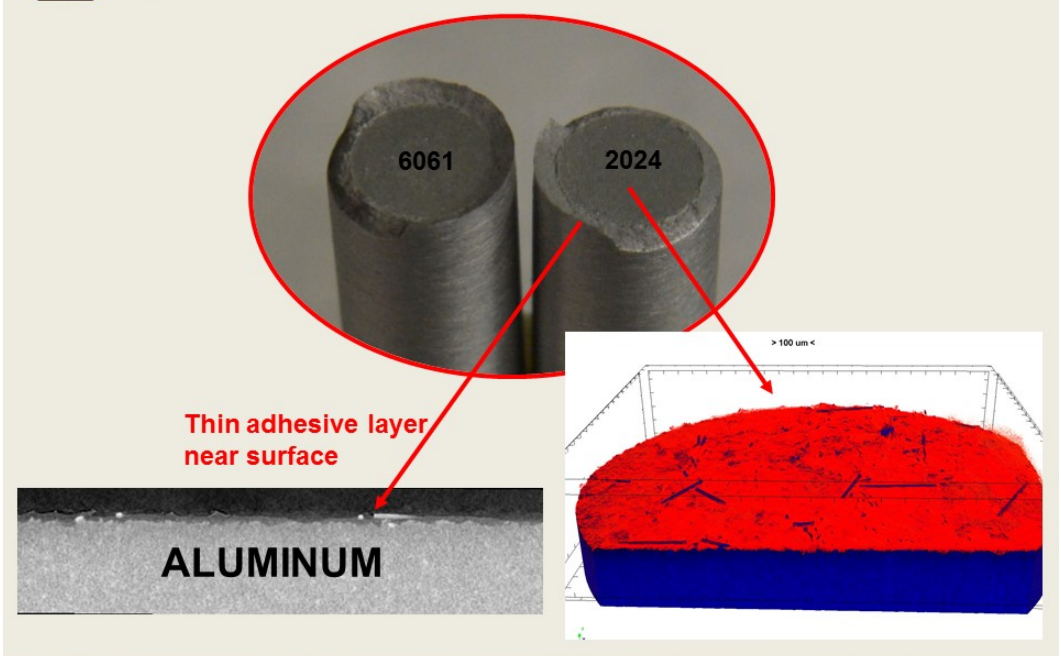
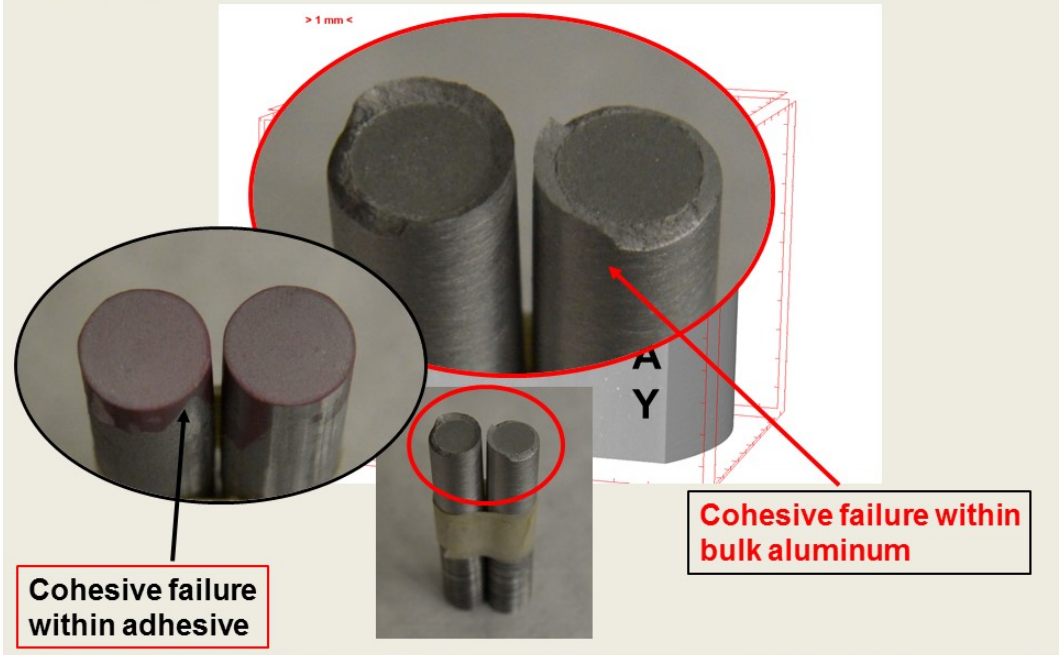
Hybrid Results



**Note: Hybrid tensile test was paused for about 5 seconds around 100 MPa and data was spliced together to create data curve shown.

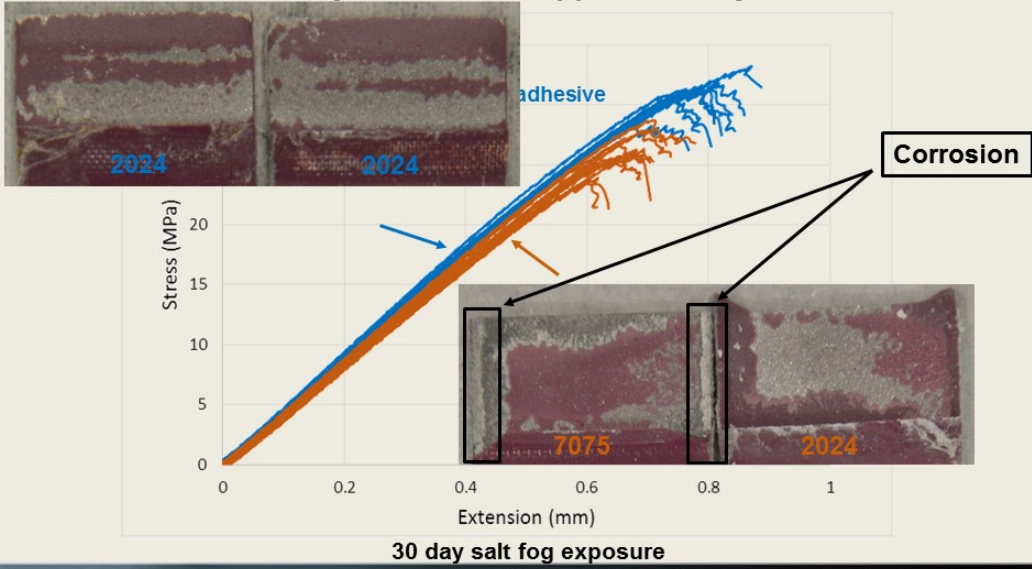
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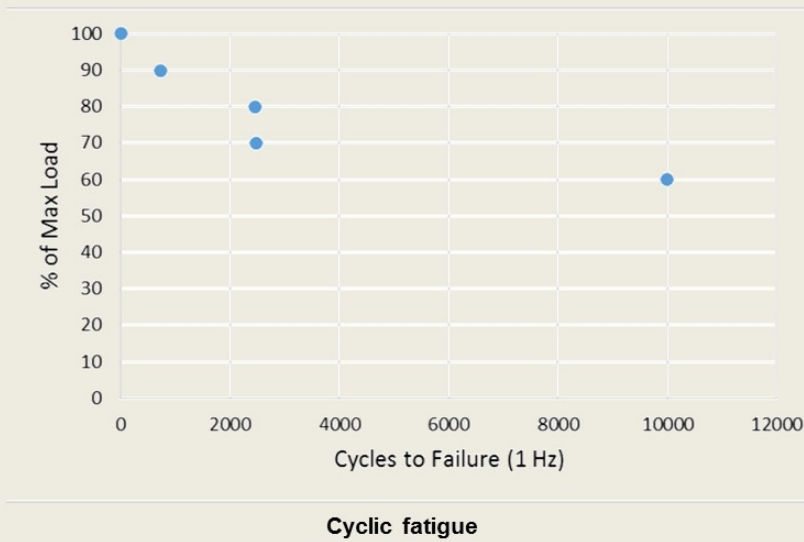




- Decreased strength and displacement retention with adhesively bonded dissimilar joints – what happens with hybrid?



- Will hybrid joint improve fatigue resistance?



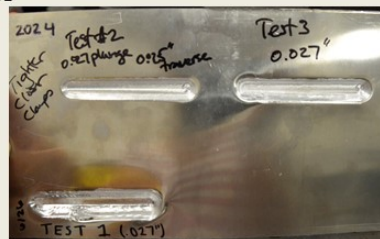


➤ Conclusions

- Geometrical limitations of solid-state techniques
- Corrosion has noticeable effect on dissimilar joints
- Opportunity for hybrid joints to increase mechanical performance

➤ Short-term Future Work

- Fabricate and test hybrid butt joints
- Fabricate hybrid lap joints
- Develop FSW and UAM methods



➤ Long-term Future Work

- Fatigue and corrosion analysis
- Full-scale testing
- Modeling



I would like to thank:

- Dr. Robert Jensen
- Daniel DeSchepper and David Flanagan (Adhesives)
- Dr. Jennifer Sietins (CT/UAM)
- Dr. Michael Kornecki (UAM)
- Dr. Kevin Doherty (FSW)
- Carl Paxton, Mark Graybeal, Blake Barnett, and Dr. Dan Kaplowitz (Cold Spray)
- David Gray, Paul Moy, and Andy Bujanda (Testing)

My progress and findings thus far would not have been possible without your contributions and assistance.



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QUESTIONS???

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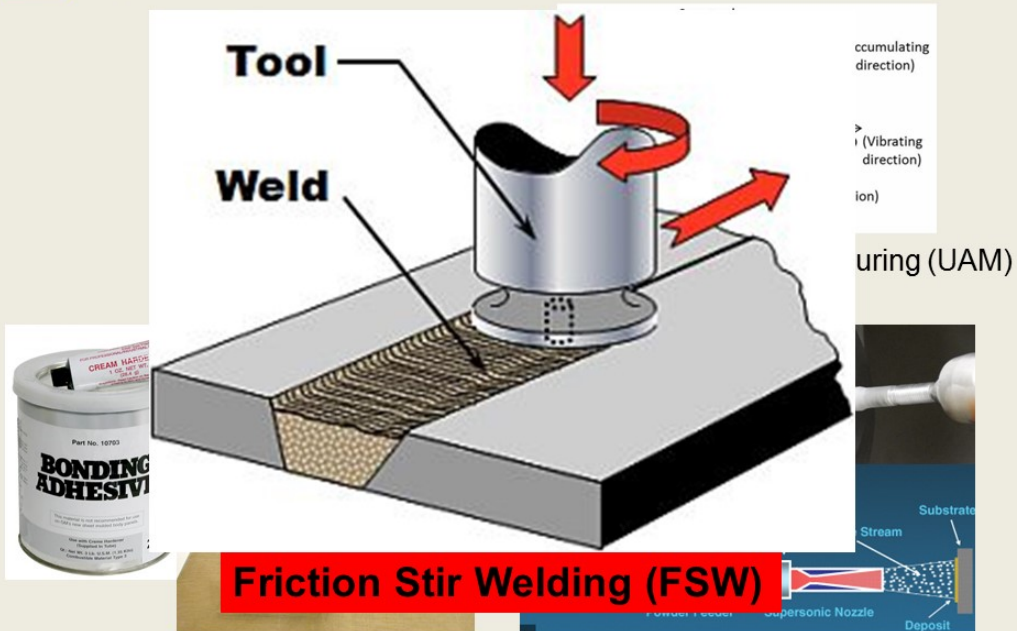
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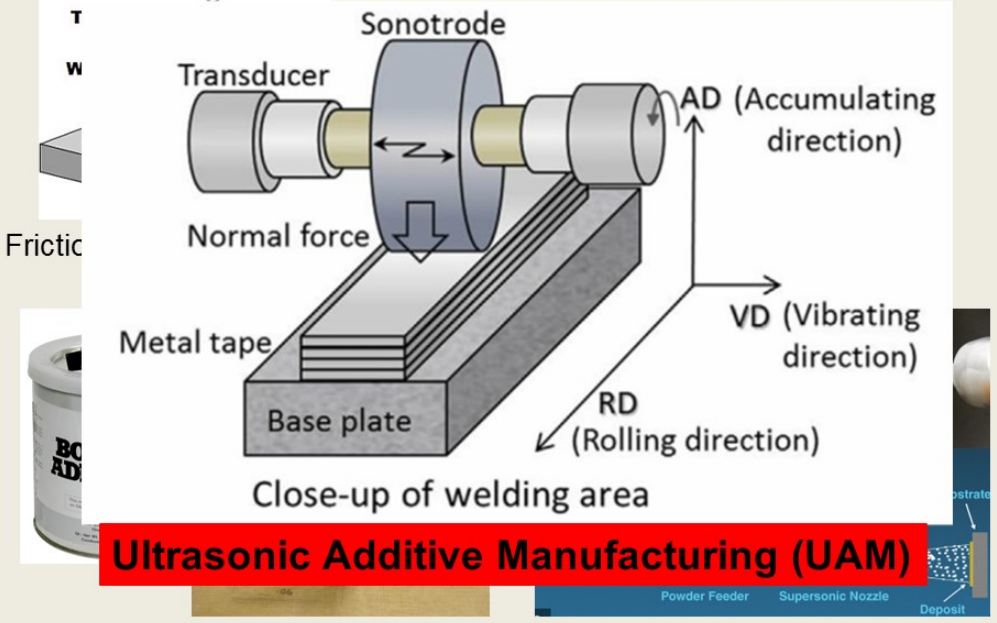
Joining Techniques

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- 80/20 bar with spring screw that can be tightened to apply pressure



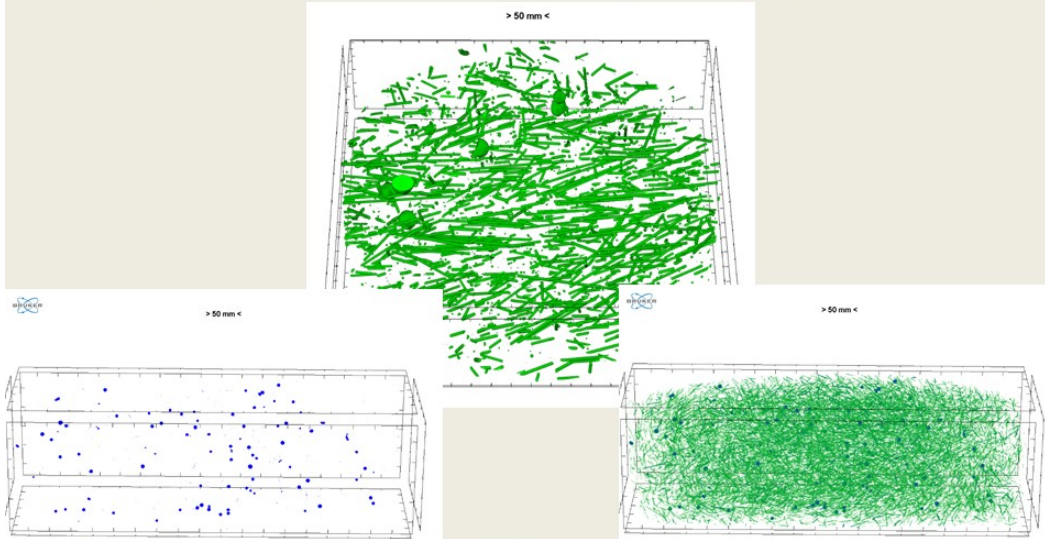


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Adhesive CT Image

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- .005" diameter glass beads to ensure even bond line thickness
- Chopped fibers for increased viscosity and strength



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References

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ISO 6922

ASTM 2095

ASTM B117

ASTM D3166

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Shear-Induced Initiation of Nitromethane

¹Brad A. Steele and ²James P. Larentzos

¹Ivan I. Oleynik

¹University of South Florida Physics Department
Tampa, FL

²Army Research Laboratory, WMRD Aberdeen
Proving Ground, MD



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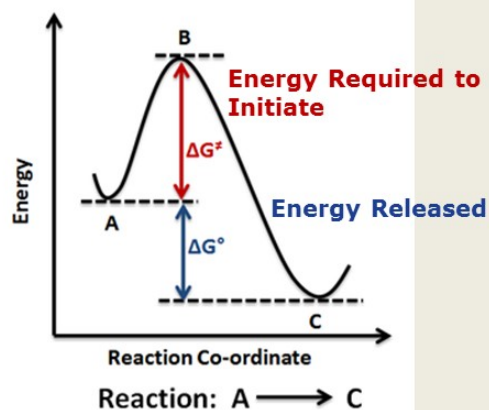
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Energetic Materials

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Trinitrotoluene (TNT)



A better understanding of the initiation of energetic materials can make them safer and allows for more advanced energy release.

The initiation is critically dependent on the reaction pathway and the energy barrier height and width.

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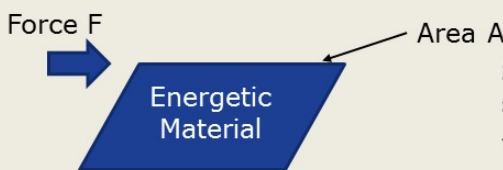


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Mechanical Initiation



- **Shock compression:** $v=v_p$ 
- **Hydrostatic compression:** 
- **Uniaxial compression:** 
- **Shear stress:** 

Force F

Area A

Shear stress
 $\tau = \frac{F}{A}$

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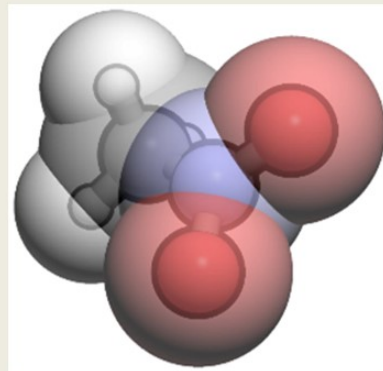
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Nitromethane



Nitromethane: (NO₂)(CH₃)

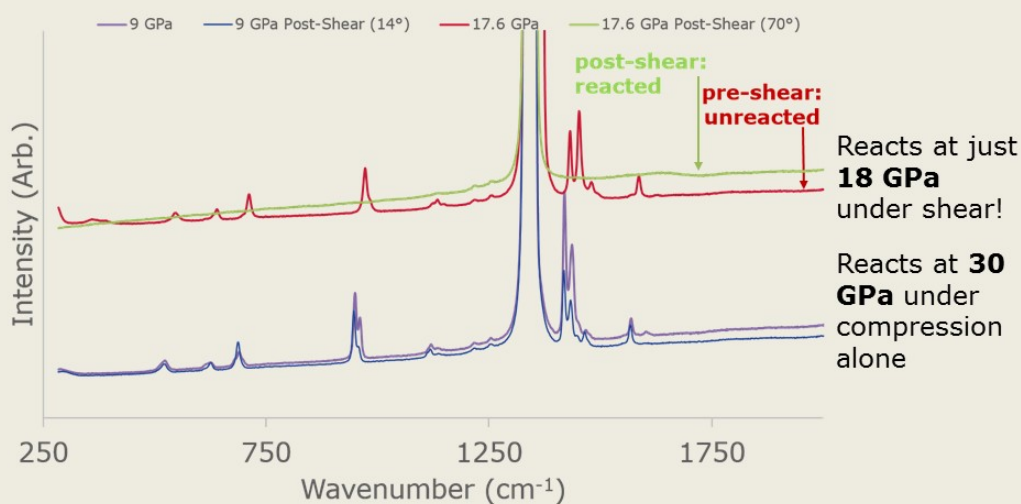
- **A prototypical EM**
- **Widely studied and experimentally well-characterized**
- **A model for understanding chemistry in larger explosives with similar functional groups**
- **No phase transitions reported in hydrostatic pressure experiments**



Nitromethane

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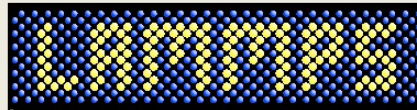
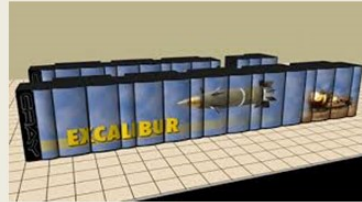
Experimental collaborators at ARL (Tim Jenkins) compress and shear NM in a rotational diamond anvil cell (RDAC) and measure Raman spectrum.

Computationally investigate the chemical reaction mechanisms that occur during the shear stress and initiation of nitromethane.

- **Develop a theoretical methodology that can accurately describe the response of nitromethane under shear stress.**
- **Investigate the role crystallographic orientation plays on the shear sensitivity of NM.**
- **The initiation of NM may be related to the presence of grain boundaries in the crystal → investigate the shear dynamics with grain boundaries in the crystal.**

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- **Atoms follow Newton's laws via classical molecular dynamics.**
- **A REACTIVE potential is used to model atomic interactions.**
- **Potential shows good agreement to experimental EOS and melting lines.**
- **Crystal orientations and grain boundaries built using code developed at ARL.**



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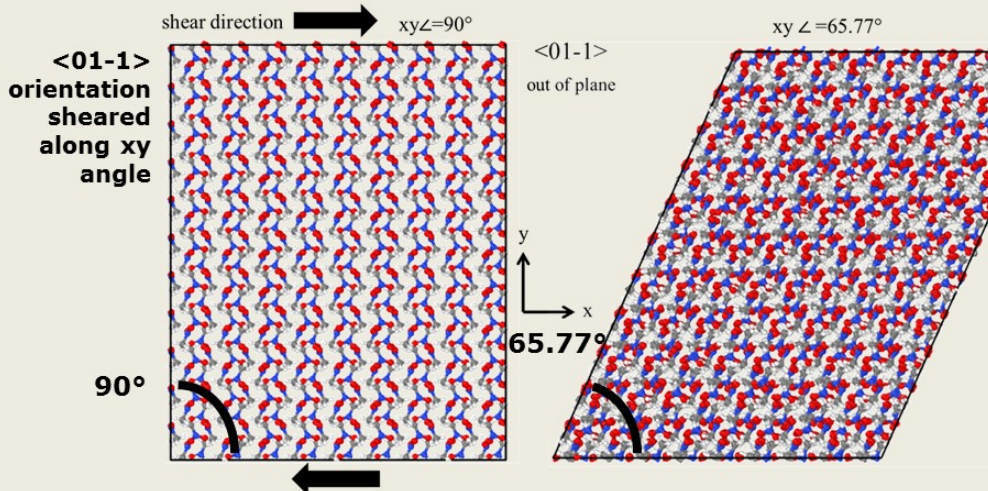
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Fully periodic crystals built with various orientations sheared along all three directions

- Initially relaxed at 20 GPa and 298 K, then sheared (shear rate = $-0.386^\circ/\text{ps}$)



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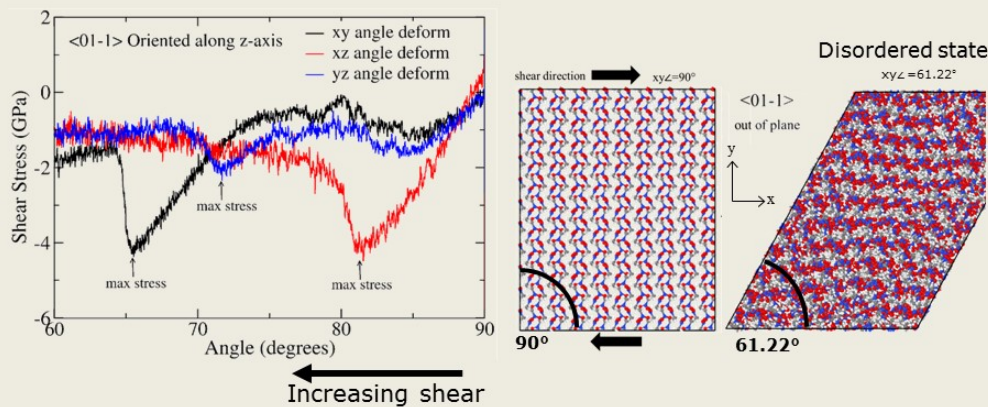
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Orientation Dependence



Significant orientation dependence

- Shear stress along sheared direction shows a gradual decrease to -2 to -5 GPa, then a sharp increase, accompanied by a transition to disordered NM state.
- Size of shear stress and shear angle are highly dependent on the orientation.



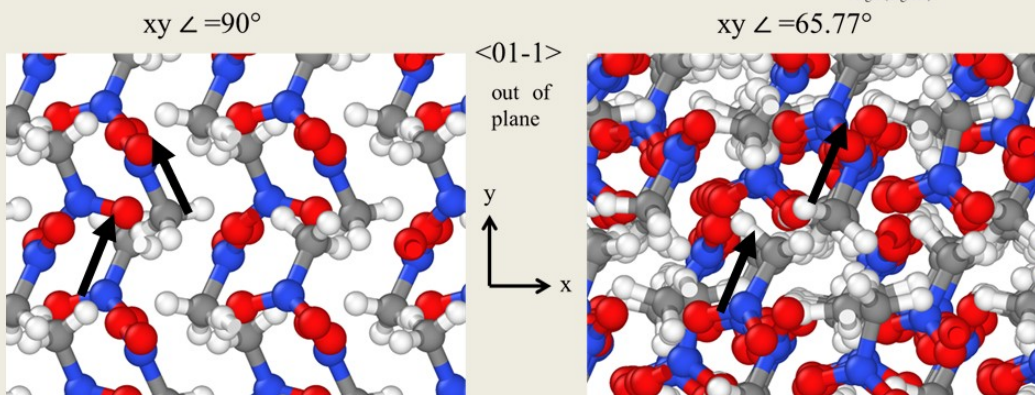
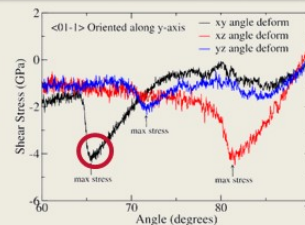
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Zoomed in Snapshot



<01-1> Orientation sheared along $xy \angle$

- When sheared along this direction, NM molecules can rotate slightly into empty space perpendicular to shear direction.





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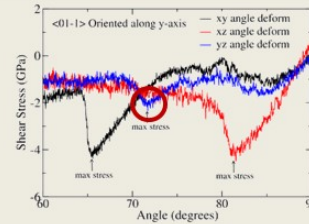
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YZ Angle Snapshots

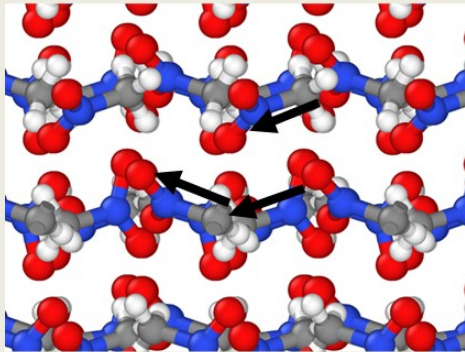


<01-1> Orientation sheared along yz

- NM molecules once again rotate to be aligned along y-axis.
- Plane of NM molecules shift slightly along shear direction (y-axis).



yz $\angle = 90^\circ$



yz $\angle = 72.77^\circ$



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Grain Boundaries



- **Several hundred bi-crystal grain boundaries (GBs) are created.**
- **Atom positions and crystal lattice relaxed at 20 GPa and 300 K.**
- **GBs are ranked according to GB energy:**

$$E = \frac{U_{GB} - U_{perfect} * N_{atoms}}{2 * Area}$$

- **Structures with lowest GB energy are chosen on which to perform shear simulations.**

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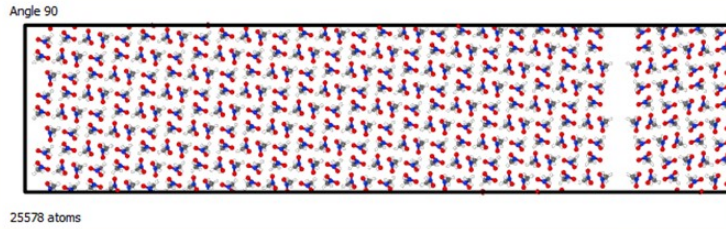


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Shear Grain Boundary



Grain Boundary:
 $\langle 011 \rangle / \langle 011 \rangle$
 along z
 $\langle 0\ 27\ -14 \rangle / \langle 0\ -27\ 14 \rangle$ along y

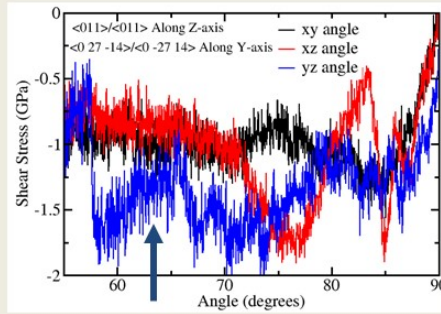


Grain Boundary

Grain Boundary

Notice that:

1. The entire grain rotates with the shear.
2. The molecules do not rotate until a very large shear angle is reached.
3. Disordered NM originates at GB and grows.

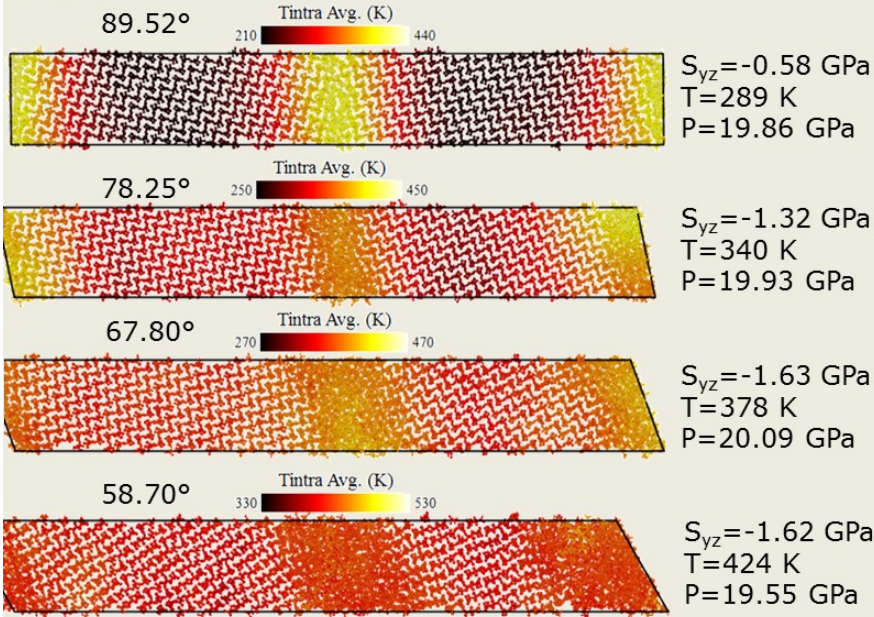


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Molecular Temperature



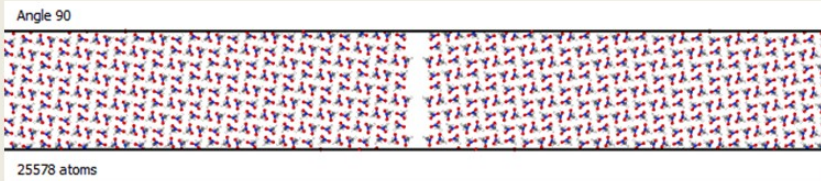
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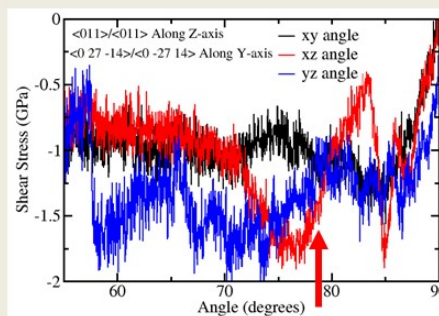
Shear Along xz



Grain Boundary:
 $\langle 011 \rangle / \langle 011 \rangle$
 along z
 $\langle 0\ 27\ -14 \rangle / \langle 0\ -27\ 14 \rangle$ along y
 *Shear direction
 into plane

Grain
BoundaryGrain
BoundaryGrain
Boundary**Notice that:**

1. Transformation to disordered state occurs suddenly throughout the entire material.
2. Stress still grows because transformation is incomplete at $\sim 80^\circ$.
3. Much different than yz direction.

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Future Work



Chemical reactions have not occurred during shear simulations!

- Perform shear simulations on polycrystalline NM.
- Investigate size dependence more thoroughly.
- Investigate time scale for reactions to occur by calculating activation energies for proposed reactions in NM.
- Investigate hydrostatic pressure dependence of results.

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- **Uncovered short-time scale shear dynamics and possibly initial stages of reaction pathway.**
- **NM transforms into a disordered material under shear stress at 20 Gpa and 298 K, but no reactions are observed.**
- **Significant orientation dependence on the shear response of NM: max shear stress 5.2-1.6 Gpa.**
- **Shear stress characterized by the ability or lack of ability for NM molecules to rotate or planes of NM molecules to shift with the shear stress.**
- **Response of NM with a GB under shear characterized by rotation of entire grain or rotation of molecules in the grain.**

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James P. Larentzos
Tim Jenkins
Betsy Rice
William Mattson

LSMB

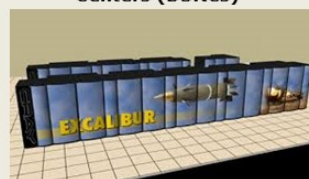
Shawn Coleman

Funding

DOD HPCMP Internship Program:
HIP-16-018
ORISE/ORAU

**Computing Resources**

DoD HPCMP
Defense Supercomputing Resource
Centers (DSRCs)



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Questions?

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Extra Slides

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Orientation <hkl>	Max S _{xy} (Gpa)	Max S _{xz} (Gpa)	Max S _{yz} (Gpa)
<1-1-1>	4.21	5.24	4.03
<10-1>	2.15	2.70	4.67
<11-1>	3.73	3.34	4.54
<110>	3.03	4.53	2.98
<010>	3.92	3.46	1.95
<1-11>	4.06	3.03	2.96
<111>	4.08	3.27	3.01
<1-10>	3.43	3.46	2.85
<01-1>	4.38	4.48	2.35
<101>	2.19	2.79	3.51
<011>	3.07	2.94	1.68
<001>	2.60	2.77	4.27
<100>	4.26	3.59	2.54

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