# Exit Presentation: Infrared Thermography on Graphite/Epoxy

By
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# Agenda

- Personal Information
- Project
  - Objectives
  - Flat bottom hole simulation
  - Flat bottom hole experiment
  - Thin delamination simulation
- Summary
  - Skills acquired
  - Future work
  - Experiences at JSC
  - After Graduation
  - Acknowledgments

# Personal Information

- Hometown: Friendswood, Texas
- University: Southwestern University
- Major: Mathematics
- Minor: Physics, Economics
- Pi Mu Epsilon, Chi Alpha Sigma, Pi Theta Kappa
- Soccer, Lacrosse, Choir, Tutoring
- MUST Intern


# Project Objectives

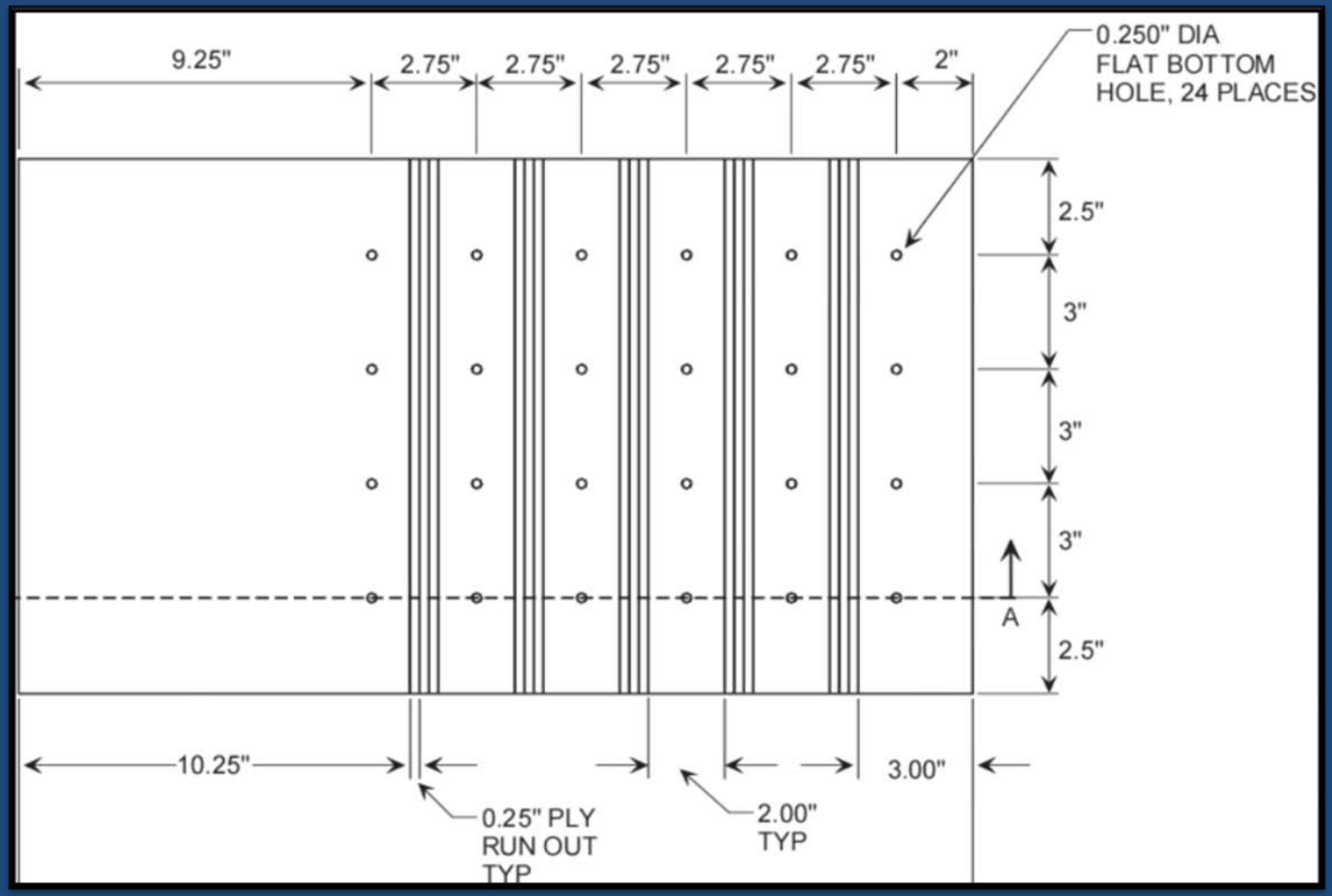
- Simulate Flash Thermography on Graphite/Epoxy Flat Bottom hole Specimen and thin void specimens.

- Obtain Flash Thermography data on Graphite/Epoxy flat bottom hole specimens

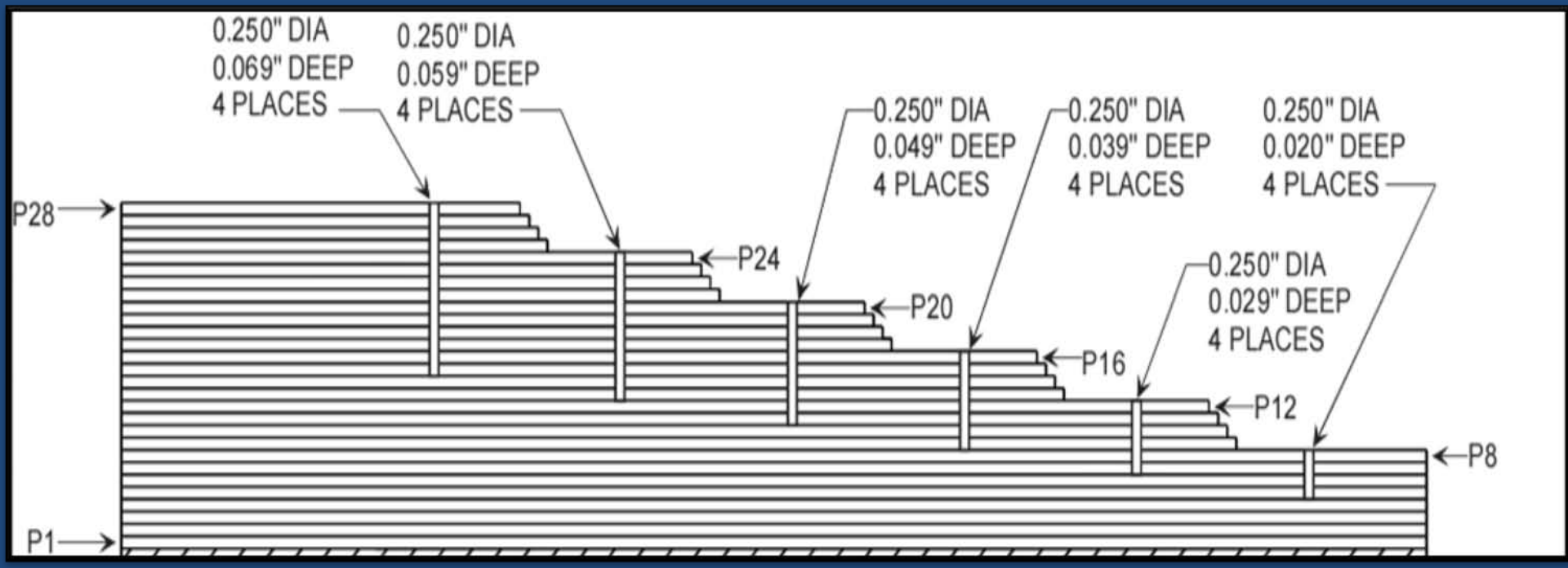
- Compare experimental results with simulation results

- Compare Flat Bottom Hole Simulation with Thin Void Simulation to create a graph to determine size of IR Thermography detected defects

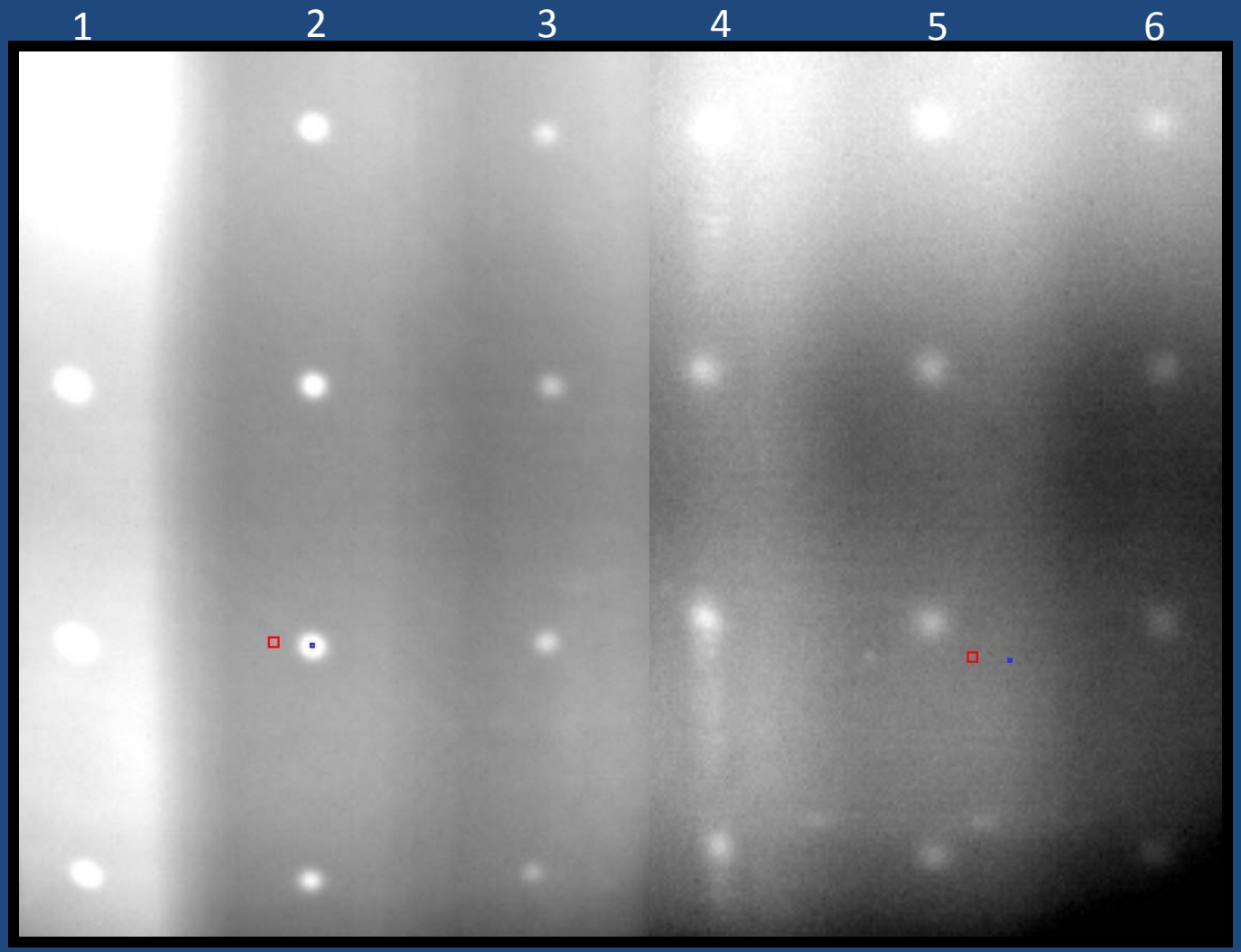
# Composite Dimensions



# Composite Dimensions



# Composite Dimensions



# Creating Flat Bottom Hole Simulation

- Simulation requirements
  - Uniform thickness
  - Defects completely inside composite
- Pixel size
  - Circular defects to square defects
  - Width in terms of pixels

| Thermal Properties of Composite | Values |
|---|---|
| Density | 1150(kg/m$^3$) |
| Heat Capacity | 0.853(J/g/K) |
| Conductivity: Z axis | 0.525(W/m/K) |
| Conductivity: X axis | 3.38(W/m/K) |
| Conductivity: Y axis | 3.38(W/m/K) |

| Thermal Properties of air | Values |
|---|---|
| Density | 1.20(kg/m$^3$) |
| Heat Capacity | 1005(J/kg/K) |
| Conductivity: Z axis | 0.026(W/m/K) |
| Conductivity: X axis | 0.026(W/m/K) |
| Conductivity: Y axis | 0.026(W/m/K) |

# Simulation Dimensions: Column 1

| Specimen | |
|---|---|
| Length, $L_x$, *[m]* | 0.1115 |
| Width, $L_y$, *[m]* | 0.064 |
| Heat exchange coef. front surface, $h_F$, *[W/(m².ºC)]* | 10 |
| Heat exchange coef. rear surface, $h_R$, *[W/(m².ºC)]* | 10 |
| Steps along X | 223 |
| Steps along Y | 128 |
| Number of layers, *i* | 1 |
| Number of defects | 4 |
| Length of each step in *X, [m]* | 5.000E-04 |
| Length of each step in *Y, [m]* | 5.000E-04 |
| Total thickness, $L_Z$, *[in]** | 0.000 |

| Layers | Layer #1 |
|---|---|
| Conductivity, $K_x$, *[W/(m.ºC)]* | 0.023557 |
| Conductivity, $K_y$, *[W/(m.ºC)]* | 0.023557 |
| Conductivity, $K_z$, *[W/(m.ºC)]* | 0.0043267 |
| Heat capacity, *C, [J/(kg.K)]* | 870.8544 |
| Density, r, *[kg/m³]* | 1576.2045 |
| Thickness, $L_z$, *m* | 1.118E-03 |
| Number of steps along Z, *n* | 22 |
| Thickness of each step in *Z, [m]* | 5.080E-05 |
| Thickness of each step in *Z, [in]** | 0.002 |

| Timing | |
|---|---|
| Type | Square Pulse |
| Heat time, $\tau_h$, *[s]* | 0.005 |
| End time, *[s]* | 6 |
| Time step, *[s]* | 0.005 |

| Heat Source | |
|---|---|
| Source in space | Exponential |
| Max heat pulse, *Q, [W/m²]* | 1.800E+06 |
| Ambient temperature, *T, [ºC]* | 30 |
| Initial temperature, $T_i$, *[ºC]* | 30 |
| Coef. of spatial distribution in X, *[1/m²]* | 0 |
| Coef. of spatial distribution in Y, *[1/m²]* | 0 |
| Heat source center in X, *[m]* | 0 |
| Heat source center in Y, *[m]* | 0 |

| Output | |
|---|---|
| Output time step, *[s]* | 0.01 |
| Surface | Front |

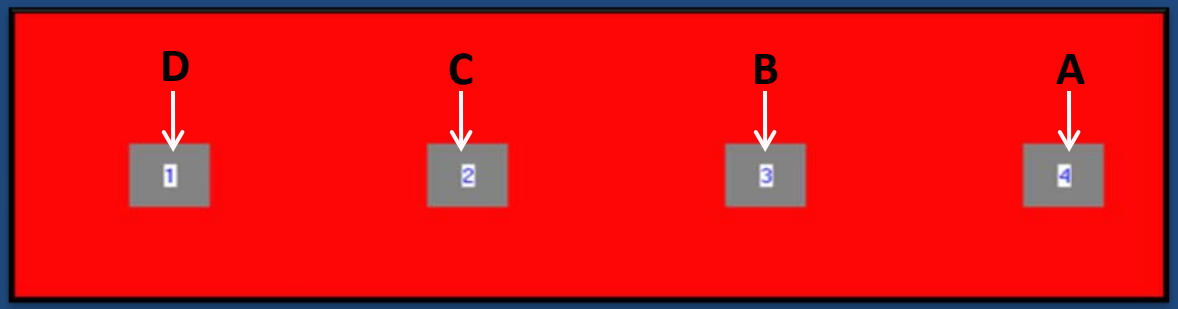
# Simulation Dimensions: Column 1

| Thermal Properties of Defects | Defect A | Defect B | Defect C | Defect D | End of Part |
|---|---|---|---|---|---|
| Conductivity, $K_x$, *[W/(m.°C)]* | 0.026 | 0.026 | 0.026 | 0.026 | |
| Conductivity, $K_y$, *[W/(m.°C)]* | 0.026 | 0.026 | 0.026 | 0.026 | |
| Conductivity, $K_z$, *[W/(m.°C)]* | 0.026 | 0.026 | 0.026 | 0.026 | |
| Heat capacity, *C, [J/kg.K]* | 1005 | 1005 | 1005 | 1005 | |
| Density, *r, [kg/m³]* | 1.20 | 1.20 | 1.20 | 1.20 | |
| Length, $L_x$, *[m]* | 5.500E-03 | 5.500E-03 | 5.500E-03 | 5.500E-03 | |
| X initial point, *[m]* | 2.950E-02 | 5.000E-02 | 7.050E-02 | 9.100E-02 | 1.115E-01 |
| Width, $L_y$, *[m]* | 5.500E-03 | 5.500E-03 | 5.500E-03 | 5.500E-03 | |
| Y initial point, *[m]* | 2.950E-02 | 2.950E-02 | 2.950E-02 | 2.950E-02 | |
| Thickness, $L_z$, *[m]* | 6.096E-04 | 7.620E-04 | 7.620E-04 | 7.620E-04 | |
| Z initial point, *[m]* | 5.080E-04 | 3.556E-04 | 3.556E-04 | 3.556E-04 | |

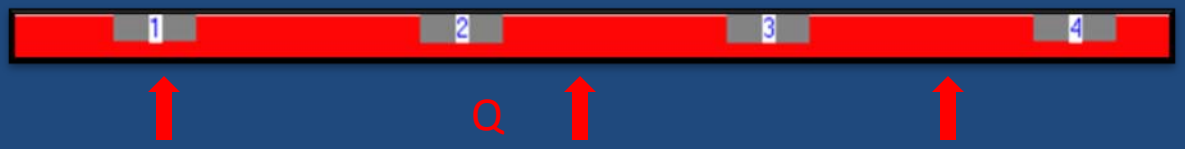
# Flat Bottom Hole Simulation: Column 1

- Simulation size

**Front view:**

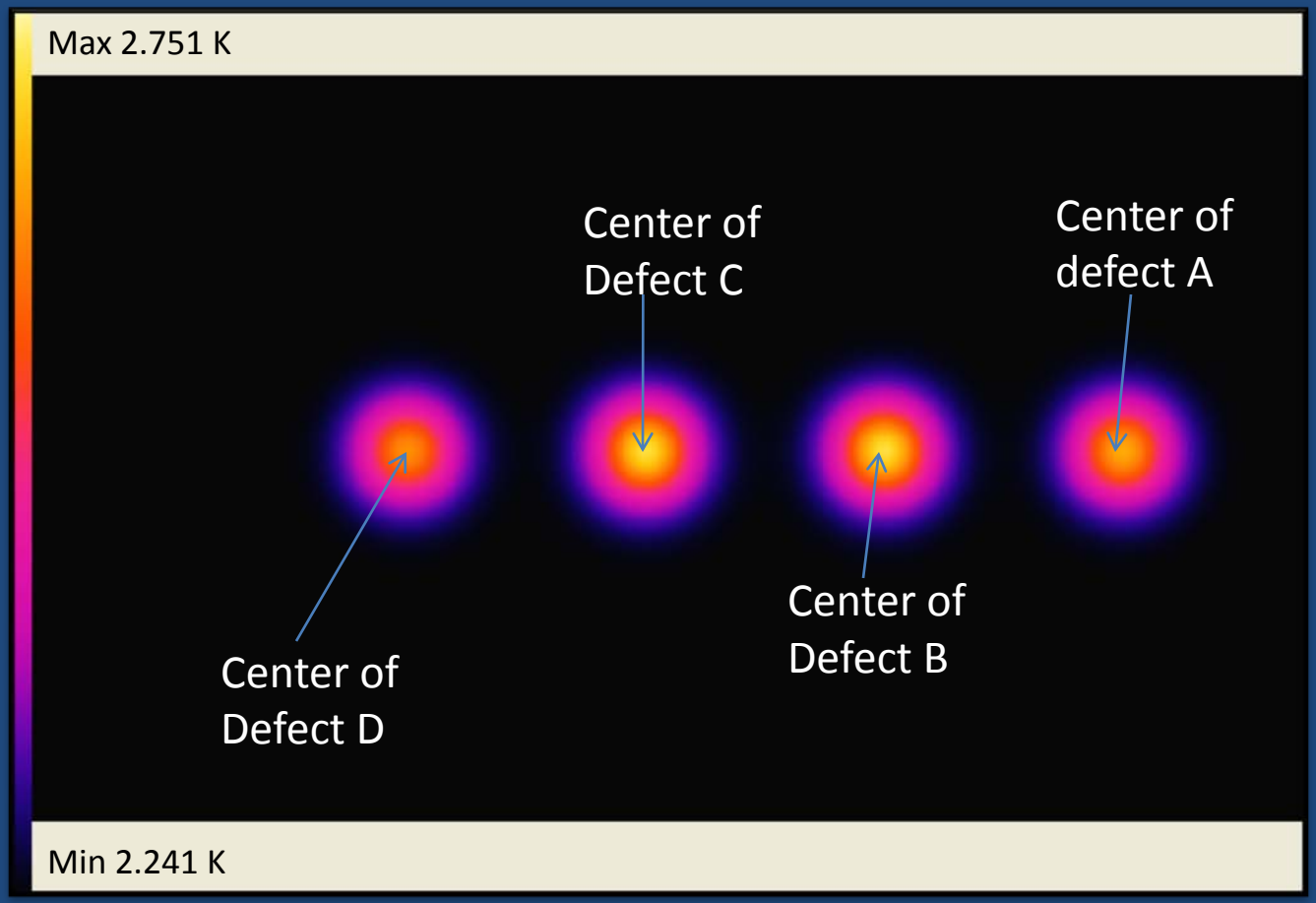



**Top view:**



# Data from Flat Bottom Hole Simulation: Column 1

## Infrared Thermography Simulation of 0.044 Inch Thick Graphite/Epoxy Composite

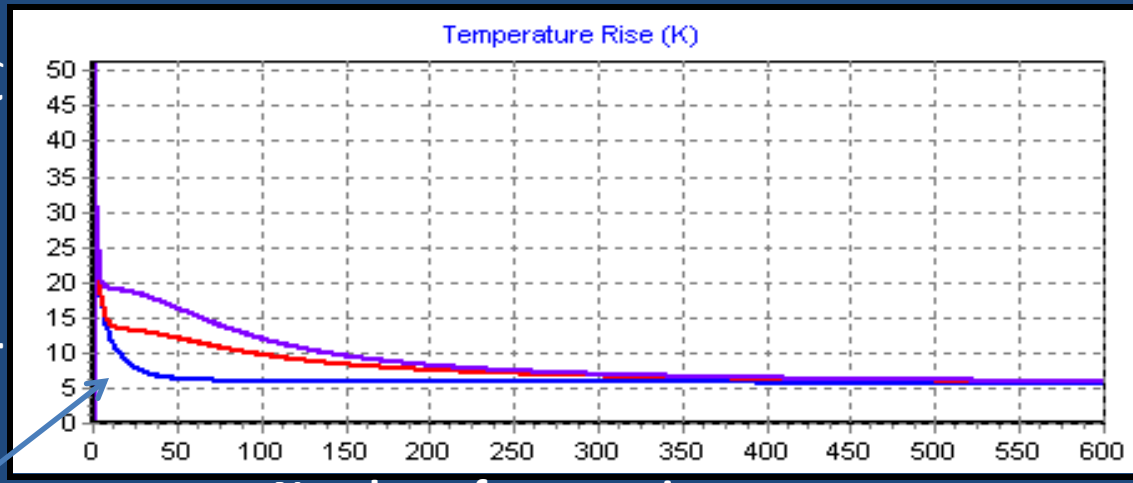


# Simulation Results: Temperature v. Time Image

- Shows the difference in temperature.
- Blue curve is reference point
- X, Y : Coordinates defect's center on simulation

| Num | x | y | Color |
|---|---|---|---|
| v 1 | 106 | 65 | |
| v 2 | 0 | 0 | |
| v 3 | 65 | 65 | |
| v 4 | 147 | 65 | |
| v 5 | 188 | 65 | |

**Temperature Rise (K)**

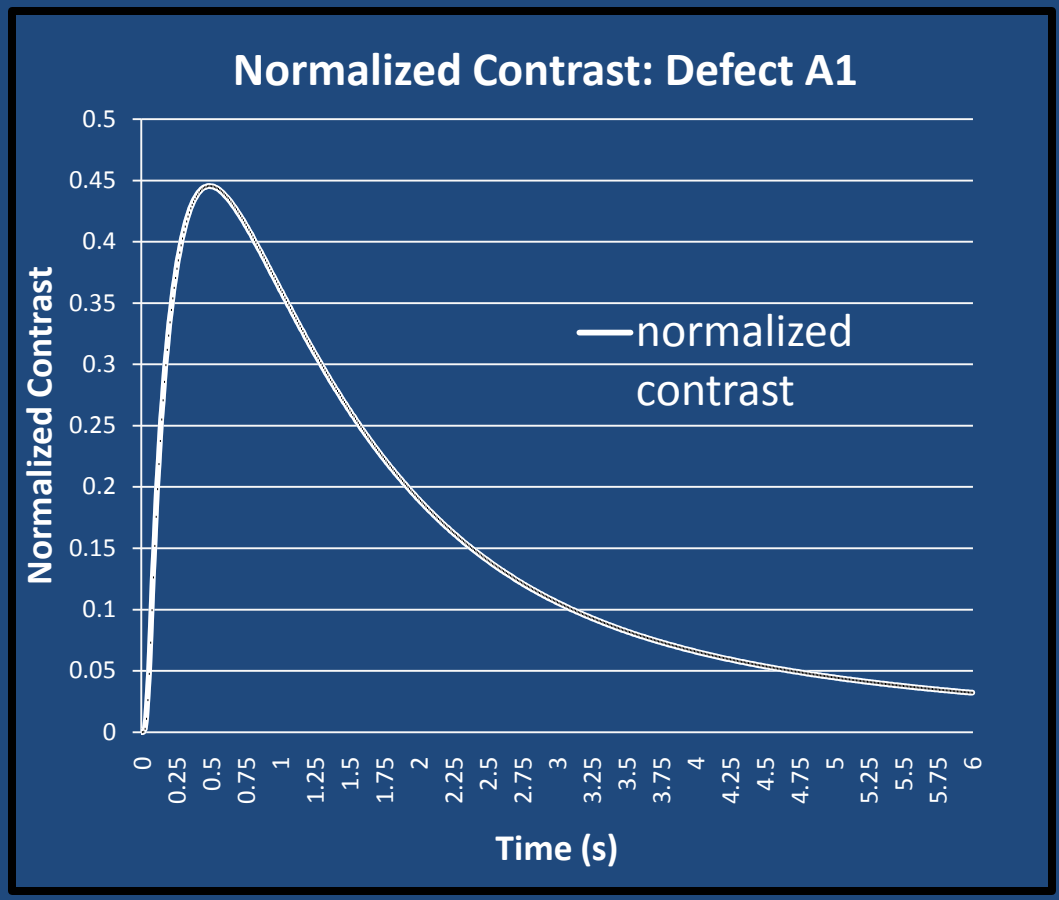



Temperature Rise for Reference point

# Normalizing Data and Graphing

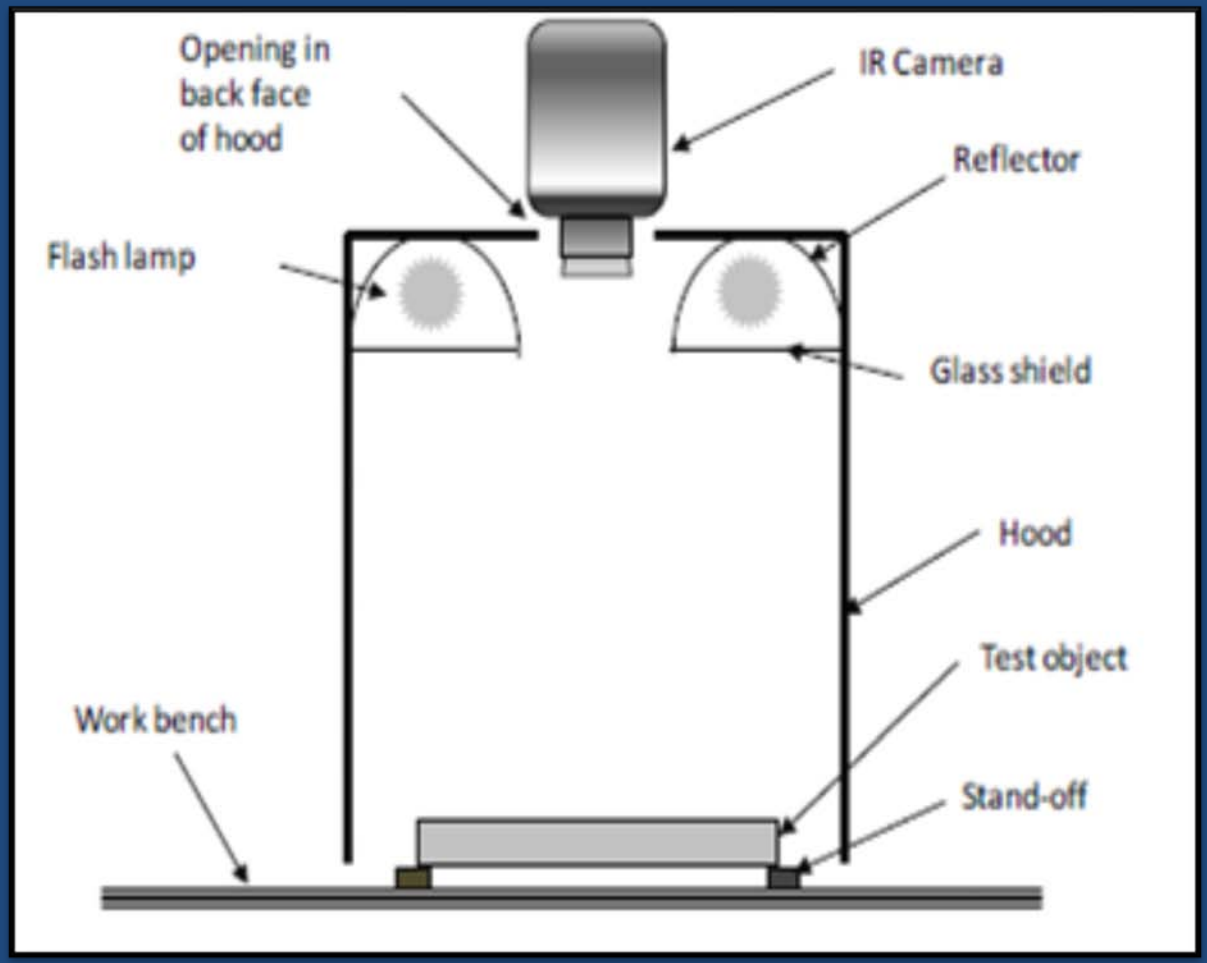
- Collect data from Temperature v. Time graph
- Convert text file to excel spreadsheet
- Normalized contrast:

$$\frac{(T_i - T_{i_0}) - (T_r - T_{r_0})}{(T_i - T_{i_0}) + (T_r - T_{r_0})}$$




T = Temperature for simulation,
Pixel intensity for experimental IR data

# Experimental Set-up



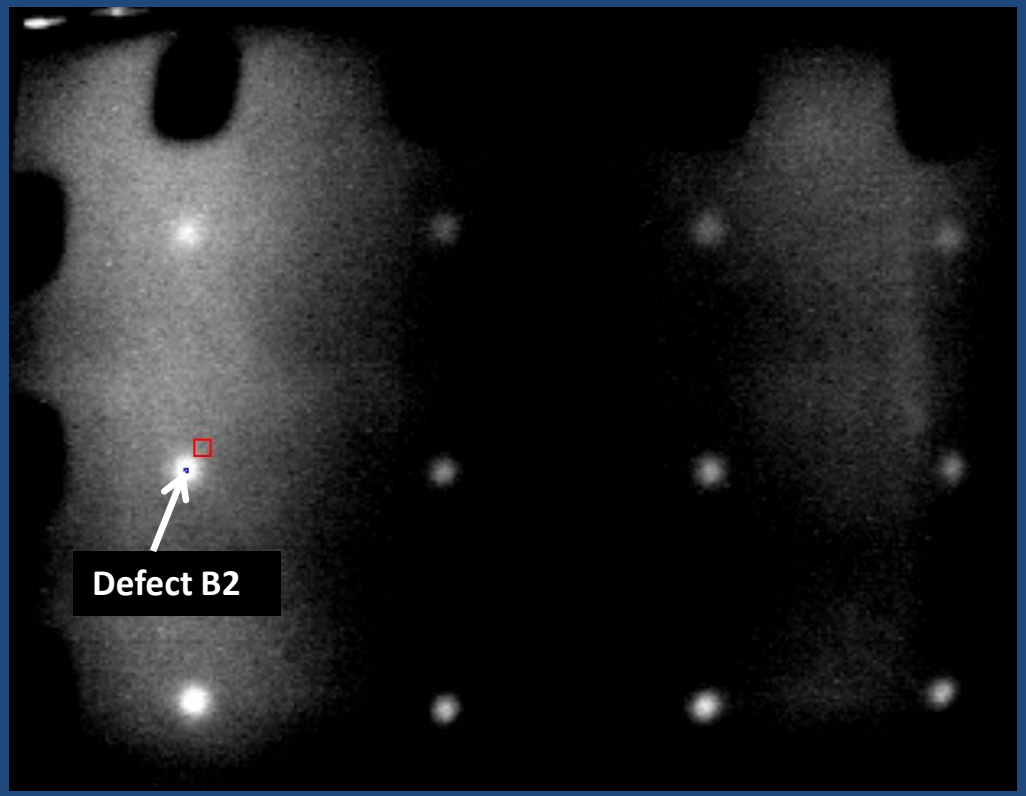
# Frames of Infrared Thermography Evaluation

**Defects A-D in Columns 1-3**

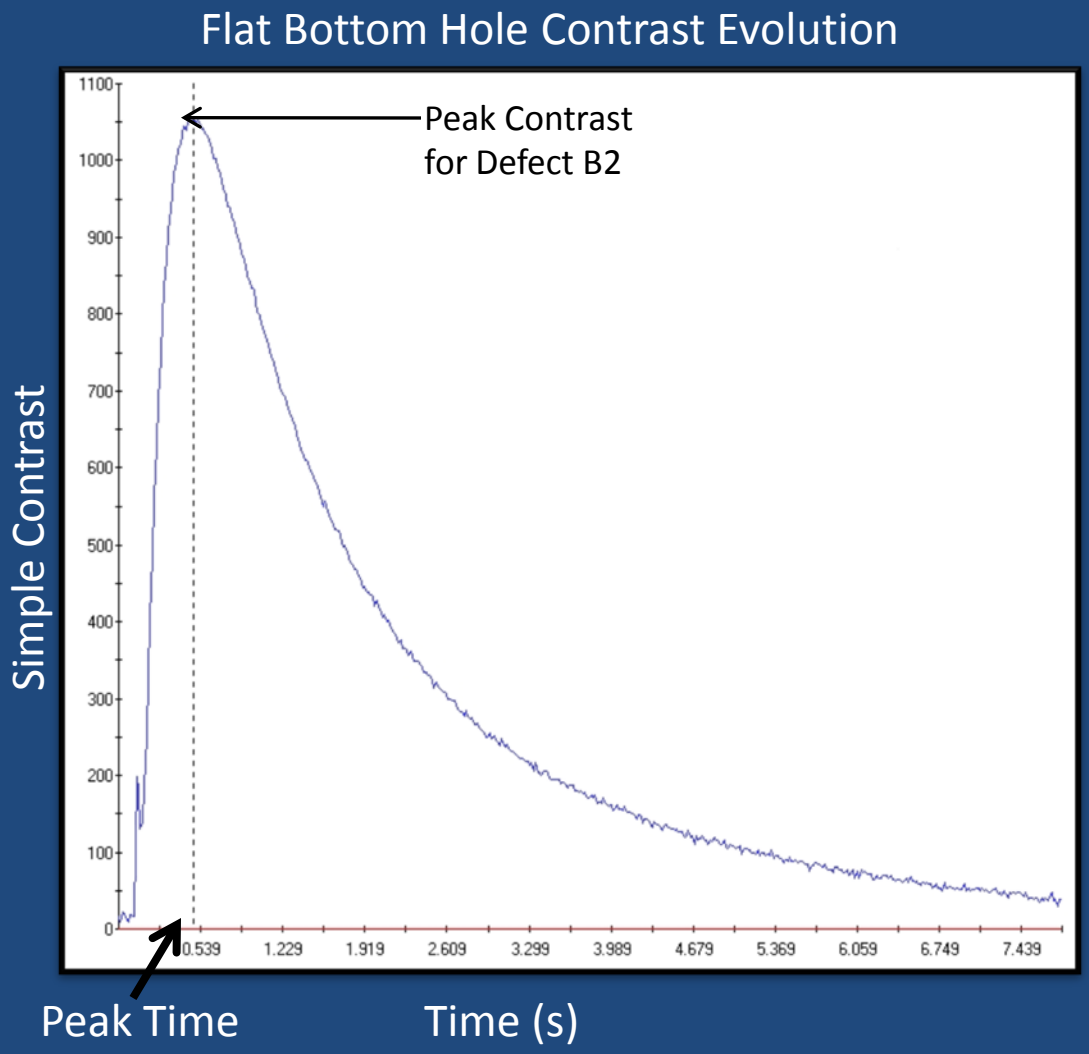
# Experimental Data

- Reference point
- Point of Interest
- Different sizes

Image Window: Flat Bottom Hole



# Simple Contrast



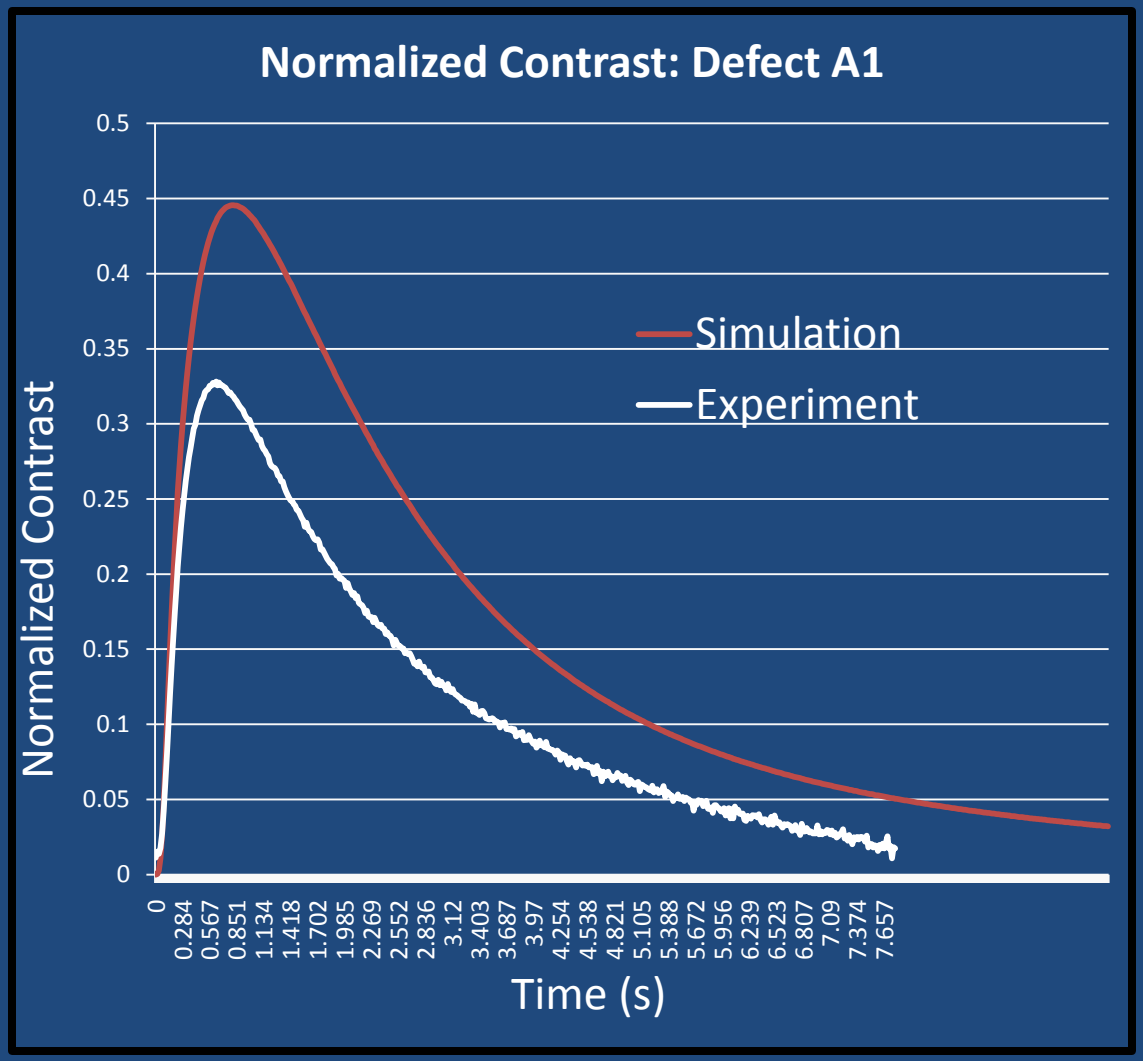

- Finding maximum simple contrast
- Saving data as text file
- Transporting data to Excel
- Creating Normalized contrast

# Calculating and Graphing Normalized Contrast

- Average pre-flash temperatures for both reference point and point of interest
- Use averages as initial temperature

| Time | Reference Point | Point of Interest | | | |
|---|---|---|---|---|---|
| -0.15 | 7240 | 7249 | | | |
| -0.133 | 7241 | 7253 | | | |
| -0.117 | 7240 | 7249 | | | |
| -0.1 | 7240 | 7249 | | | |
| -0.083 | 7239 | 7251 | | | |
| -0.067 | 7240 | 7254 | | | |
| -0.05 | 7239 | 7247 | | | |
| -0.033 | 7241 | 7255 | | | |
| -0.017 | 7239 | 7250 | | | |
| | 7239.889 | 7250.778 | | | |
| | | | Reference Point* | Point of Interest* | Normalized Contrast |
| 0 | 15314 | 15210 | 8074.111 | 7959.222 | -0.00717 |
| 0.017 | 12669 | 12572 | 5429.111 | 5321.222 | -0.01004 |
| 0.033 | 11469 | 11406 | 4229.111 | 4155.222 | -0.00881 |
| 0.05 | 10781 | 10742 | 3541.111 | 3491.222 | -0.00709 |
| 0.067 | 10335 | 10313 | 3095.111 | 3062.222 | -0.00534 |
| 0.083 | 10012 | 9992 | 2772.111 | 2741.222 | -0.0056 |
| 0.1 | 9772 | 9758 | 2532.111 | 2507.222 | -0.00494 |

# Comparison and Correction of Simulation

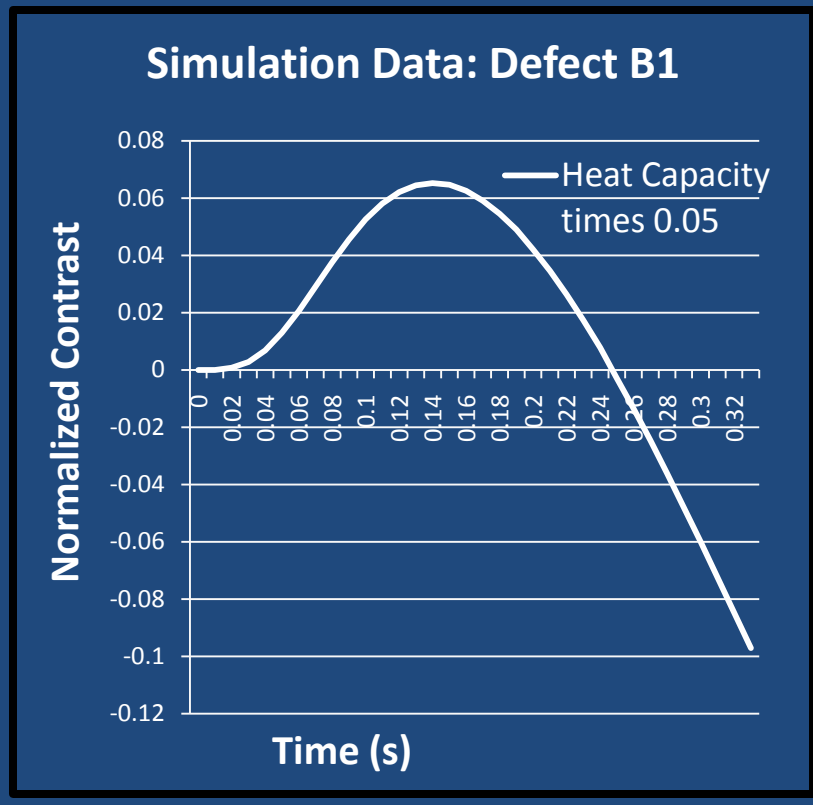



- The Normalized contrast for the original simulation and experimental data
- Analysis
- Peak Contrast
- Peak Time
- Correction of simulation data to more accurately portray experimental data

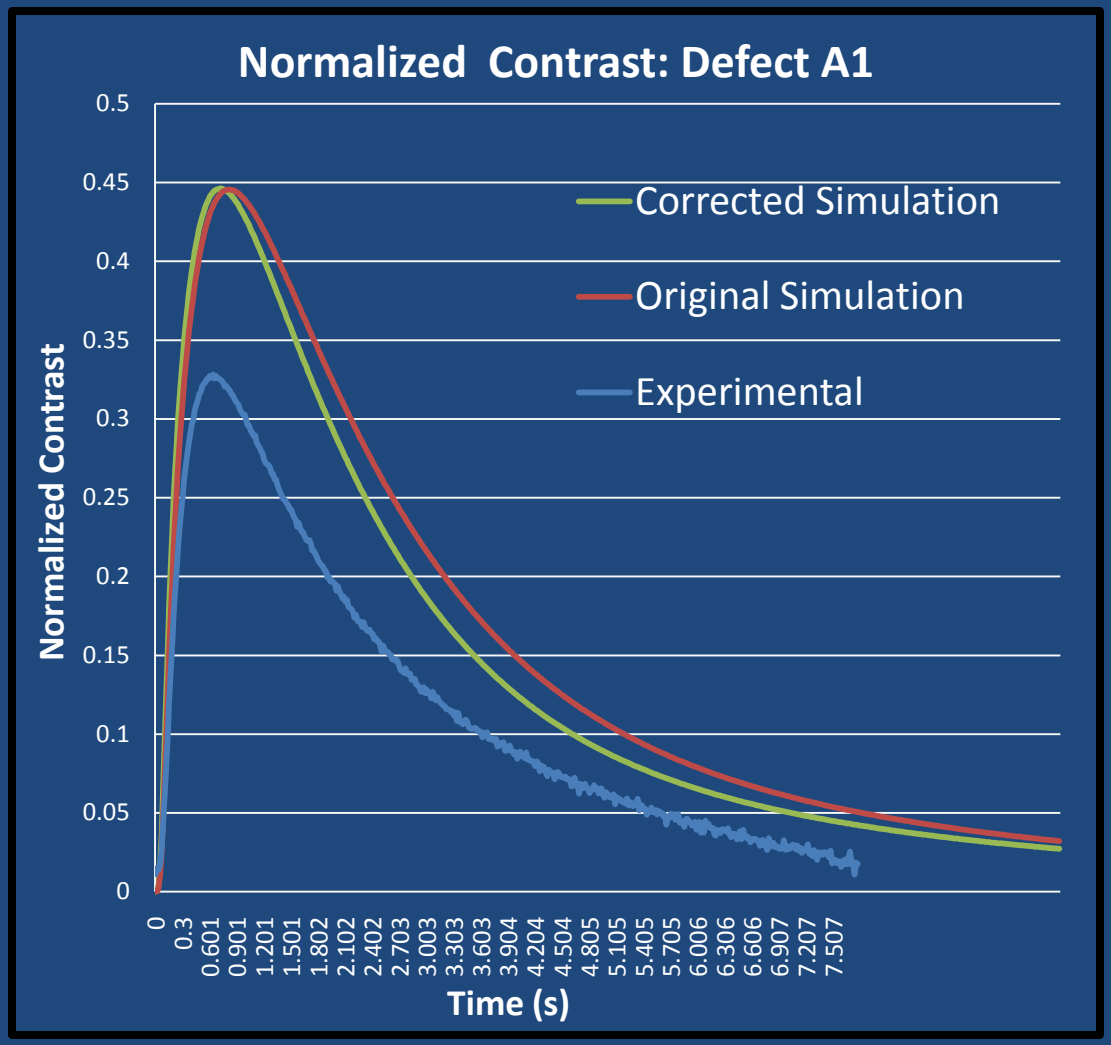
# Correction of Simulation

- Diffusivity: $\alpha = \kappa / (\rho \times C)$
- Change properties of material
  - Change Specific Heat
  - Change in Conductivity
  - Could change Density
- Final Decision

| Thermal Properties of Composite | Original Values | Final Values |
|---|---|---|
| Density | 1150(kg/m$^3$) | 1150(kg/m$^3$) |
| Heat Capacity | 0.853(J/g/K) | 0.853(J/g/K) |
| Conductivity: Z axis | 0.525(W/m/K) | 1.28(W/m/K) |
| Conductivity: X axis | 3.38(W/m/K) | 3.85(W/m/K) |
| Conductivity: Y axis | 3.38(W/m/K) | 3.85(W/m/K) |



# Corrected Simulation




- Corrected simulation
- Comparison between original simulation, corrected simulation, and experimental data

# Sources of Differences

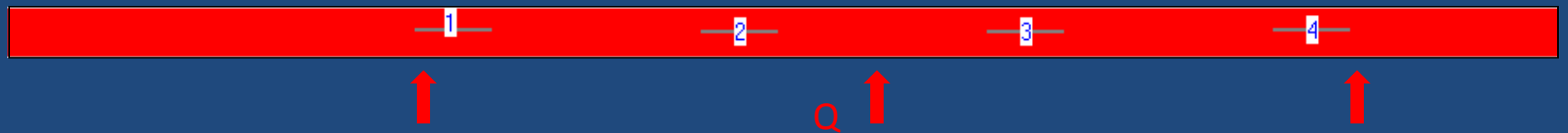
- Simulation contrast is based on temperature versus time. Experimental contrast is based on pixel intensity versus time.
- Experimental Flash vs. Simulation Flash
  - Experimental flash envelope has a sharp rise and slow decay
  - Simulation flash is a square pulse
- Experimental factors
  - Experimental data is more sensitive to pixel size. Get smaller pixel intensity for a larger pixel
  - Uneven flash causes some lateral heat flow
  - Part has a surface texture causing lateral heat flow
- Emissivity
  - The specimen emissivity was measured to be 0.9 and provides lower (< 5%) experimental contrast
- Simulation inaccuracies (model approximations, boundary condition approximations, no lateral heat flow)

# Creating Thin Delaminations

- Change depths of the defects, but leave the initial points unchanged.
- Input data into ThermoCalc-6L
- Run simulation

Flat Bottom Hole Simulation:


Thin Delamination Simulation:



# Collecting Data

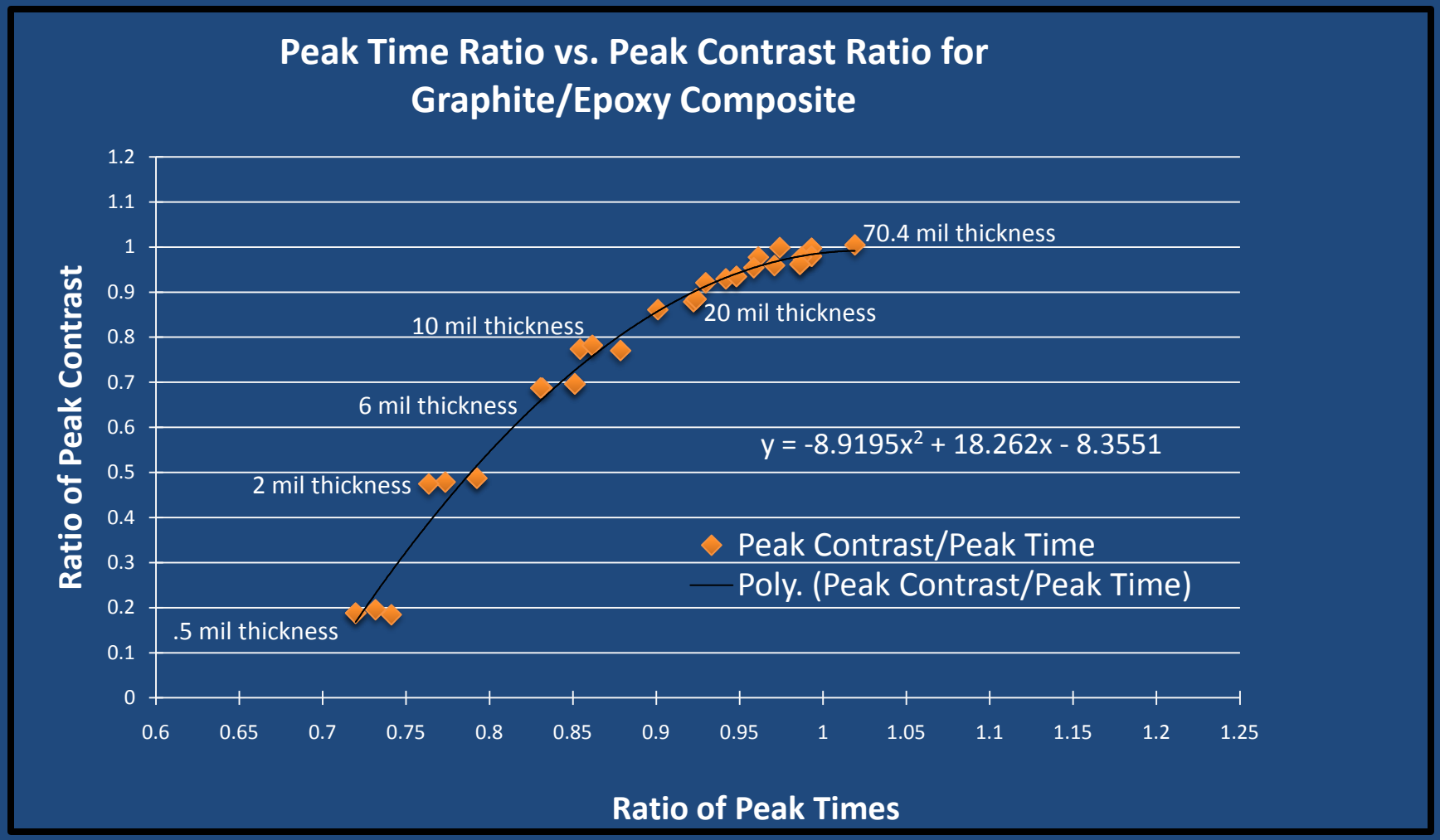
- Same as for the flat bottom hole simulation
  - Collect data from Temperature v. Time graph for each defect
  - Convert the text file to excel spreadsheet compatible
  - Generate normalized contrast graph

# Comparison of Simulations

- Comparing flat bottom hole simulation to thin delamination simulation

- Compare and graph the peak contrast ratio and peak time ratio
  - Thin delamination/Flat bottom hole

# Peak Contrast Ratio and Peak Time Ratio



# Future Work

- Make controlled impacts to make thin delaminations
- Evaluate delaminations with Infrared Thermography
- Evaluate delaminations with Ultrasonic Techniques
- Section the specimen at delaminations
- Determine actual size of delaminations
- Compare actual results with simulated results
- Determine accuracy of the simulation

# Skills Acquired

- Learned Thermodynamics
  - Theory and application
    - IR temperature measurement
- Infrared Thermography NDE
  - Simulation
  - IR Experimental data acquisition and analysis
- Eddy Current
- Ultrasonic Testing
- Time management
- Work hours
- Technical paper

# Experiences at JSC

Building 14:

Boom Tower

Ellington Field

Guppy

Building 1

ONWG Meetings

Volunteering

Food Bank

Tutoring


CLPC
Day of Service

Movie Night


Mission Control

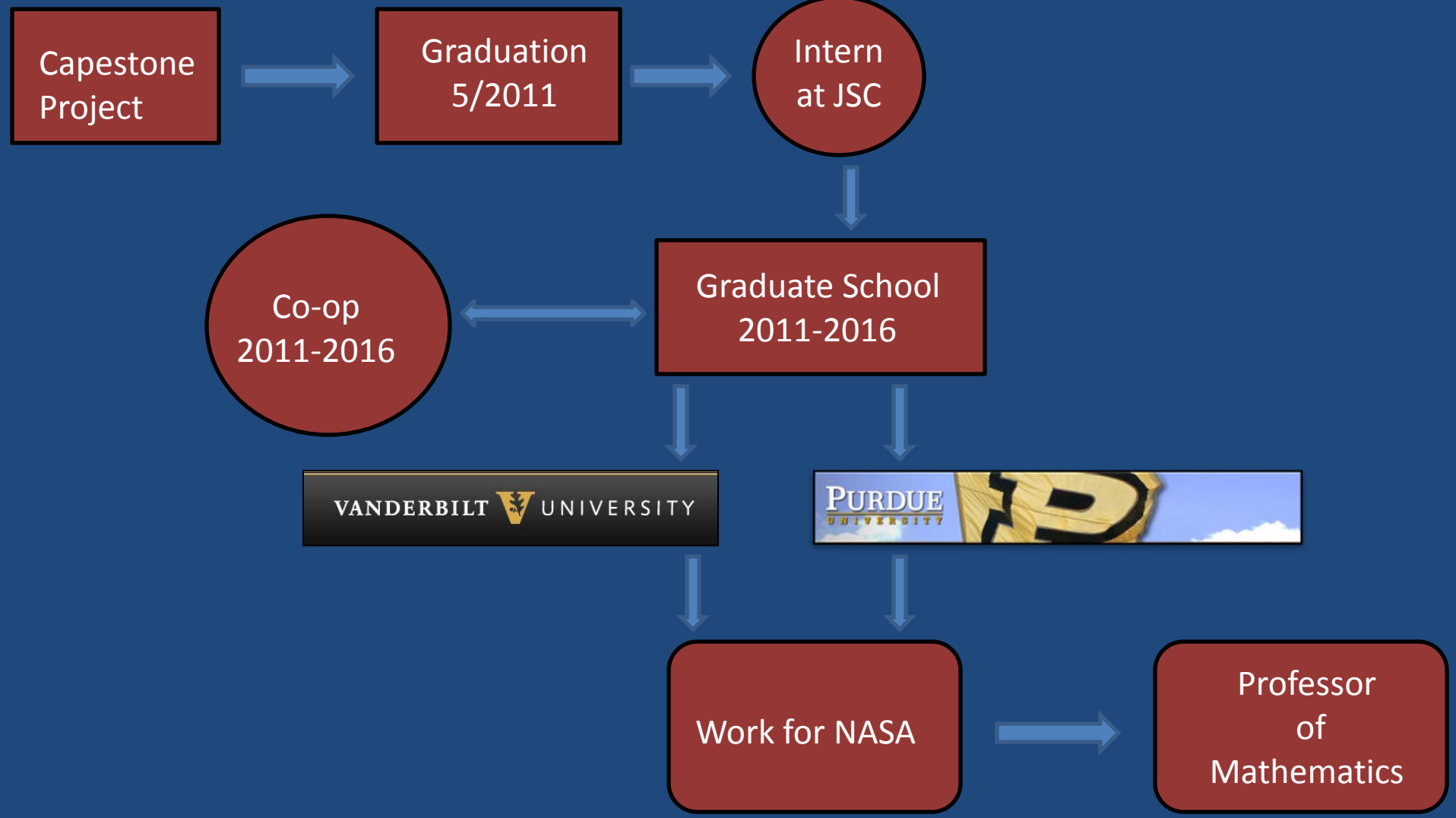
Apollo

NBL

MLS All-Stars vs


Musicals

# After Graduation



# Acknowledgements


- Parents and Family
- Mentors: Ajay Koshti & David Stanley
- Ovidio Olveras, Eddie Pompa, Norman Ruffino, Rodrigo Devivar, John Figert, Budd Castner, Mike Kocurek, Denise Plantier, Erica Worthy,  Joseph Prather
- MUST Point of Contact: Cornelius Johnson

# Exit Presentation: Infrared Thermography on Graphite/Epoxy

Thank You