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Characterization of Machine Gun Barrel Temperature and Stress Conditions Through Correlation of Testing and Numerical Methods

Presented at:
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UNPARALLELED COMMITMENT & SOLUTIONS

Act like someone's life depends on what we do.

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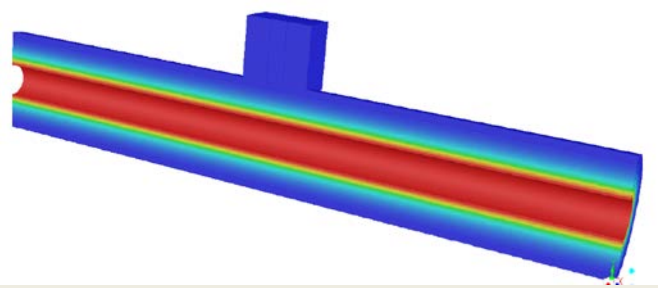
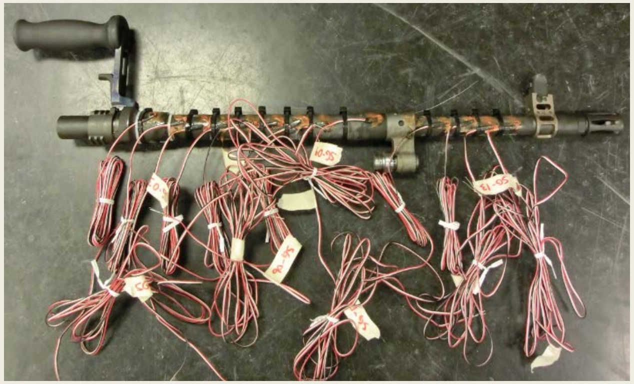
Agenda

- Purpose
- Thermal Characterization
  - Test Methodology
  - Test Observations
  - Numerical Methods
  - Results / Discussion
- Stress / Strain Characterization
  - Test Methodology
  - Test Observations
  - Numerical Methods
  - Results / Discussion
- Thermal Stress
- Conclusions, Takeaways, Recommendations
- Questions

Purpose

- Background
  - More complete understanding of bore thermal and structural behavior is desired in order to produce higher performing, lighter weight barrels
  - It is known that many barrels will survive conditions in which they are predicted to fail
  - AMCP 706-252[1] used for numerical stress analysis – based on Lame's thick walled cylinder calcs, assumes steady state, elastic. Others also developed.
  - Multiple analytical methods for barrel temperature developed over the years, CFD being the most sophisticated
  - Little work done in validating analytical/ numerical methods – stress and temperature at the bore surface are difficult to measure
- Purpose
  - Characterize the temperature and stress in a 7.62mm, M240L long machine gun barrel during various live fire events
  - Correlate and validate analytical / numerical solutions
  - Research potential alternate analysis methods

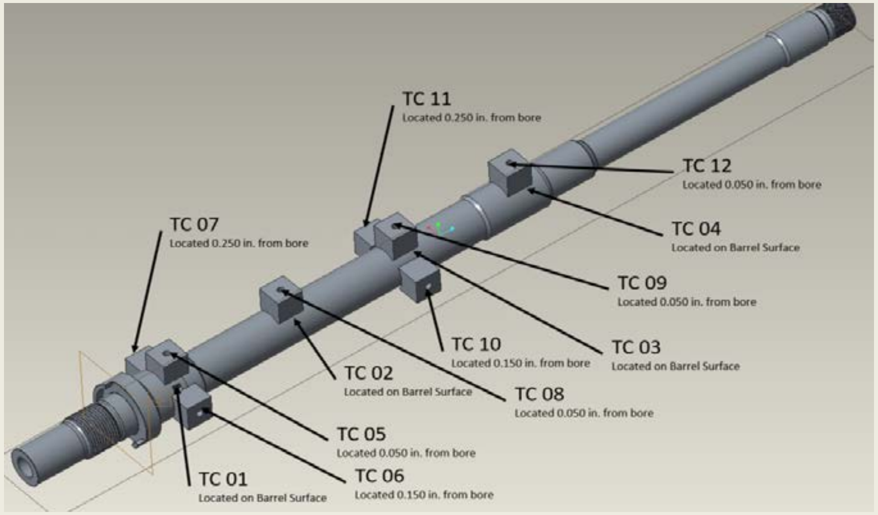




[1]AMC Engineering Design Handbook: Gun Tubes, AMCP 706-252, U.S. Army Materiel Command, 1964.

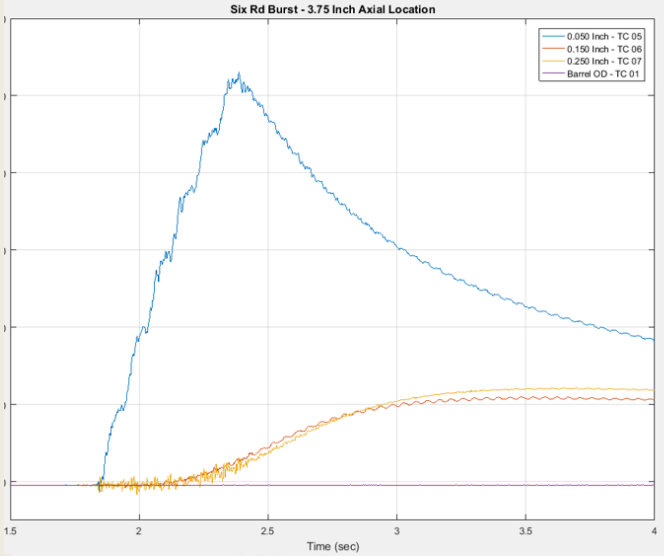
Temperature Characterization – Test Methodology

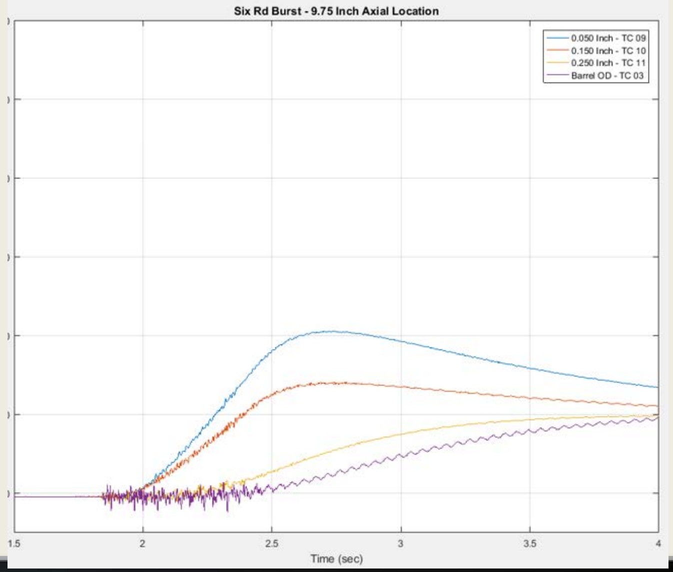
- Modified Barrel to Mount In Wall Thermocouples (IWTCs) from Veritay Technology, Inc.
- 3 inch spacing, IWTC's placed at groove location
- Thermocouples throughout barrel wall (0.050, 0.150, 0.250, barrel surface)
- Sampled at 10kHz
- Firing scenarios – Single, 6rd, 12rd, Sustained, Rapid, Final Defensive, Cyclic



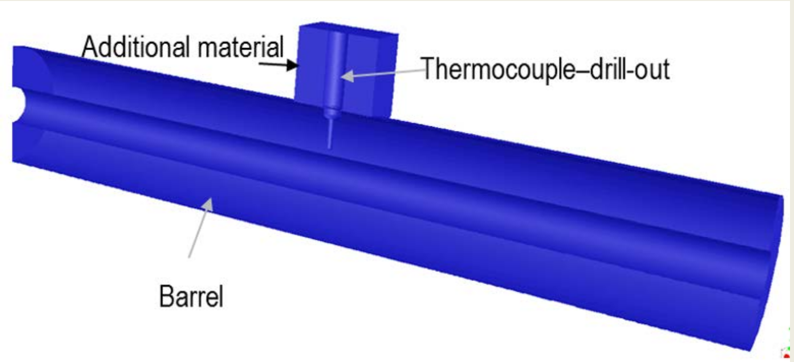
Temperature Characterization – Test Observations

- IWTCs were very sensitive to installation
  - Position (tip depth)
  - Lift off if not tight enough
  - Damaged tip if too tight – resulted in bad readings if contact made on shaft of tip
- Bottom of mounting hole – 0.043” diameter
  - Several drills broke during machining
  - Had to use a bushing at the bottom of the hole to get the 0.043 dia
- Zero Shift – steady state not the same for all thermocouples
  - Resulted in bad measurements

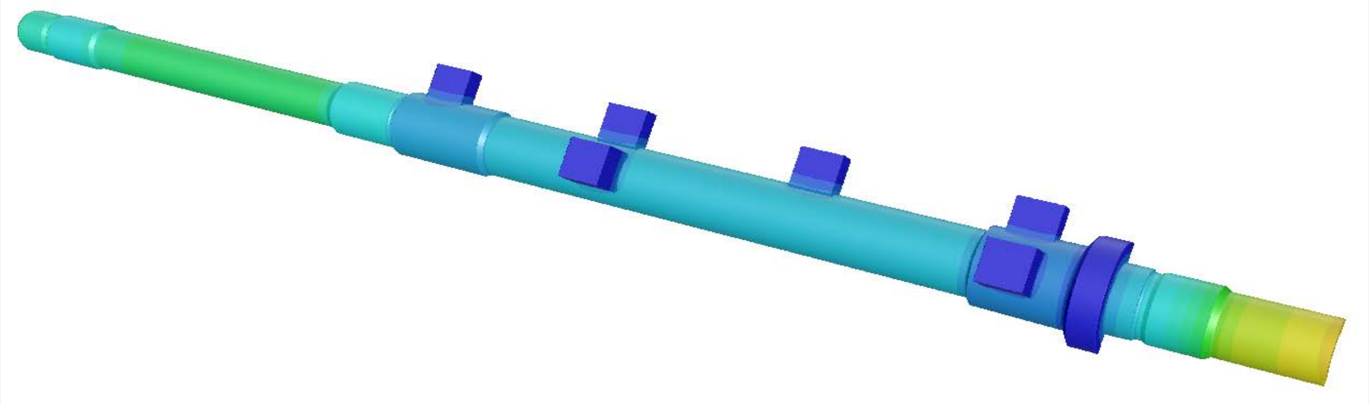




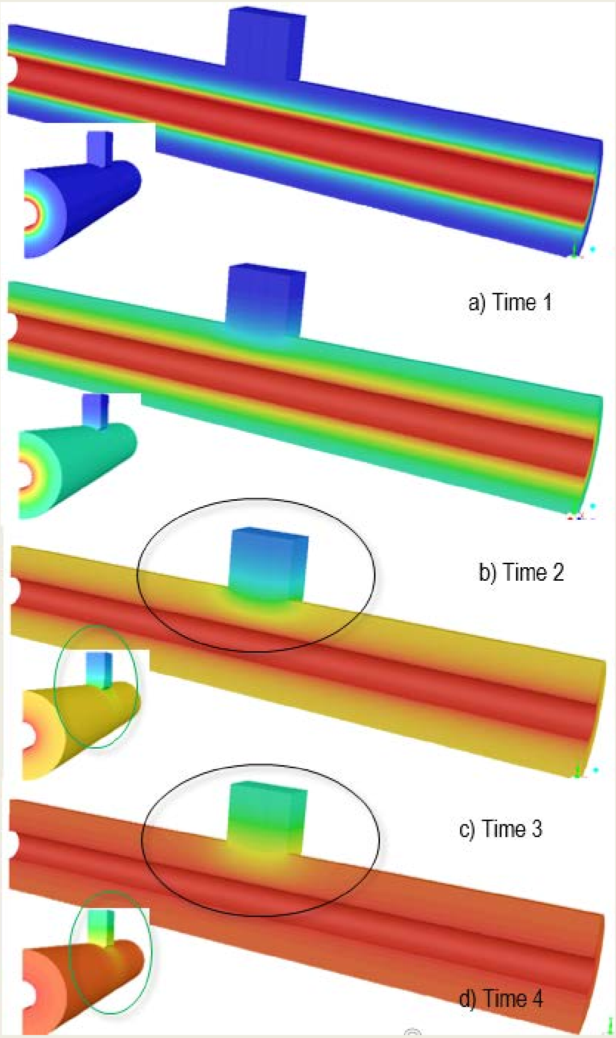
Temperature Characterization – Numerical Methods



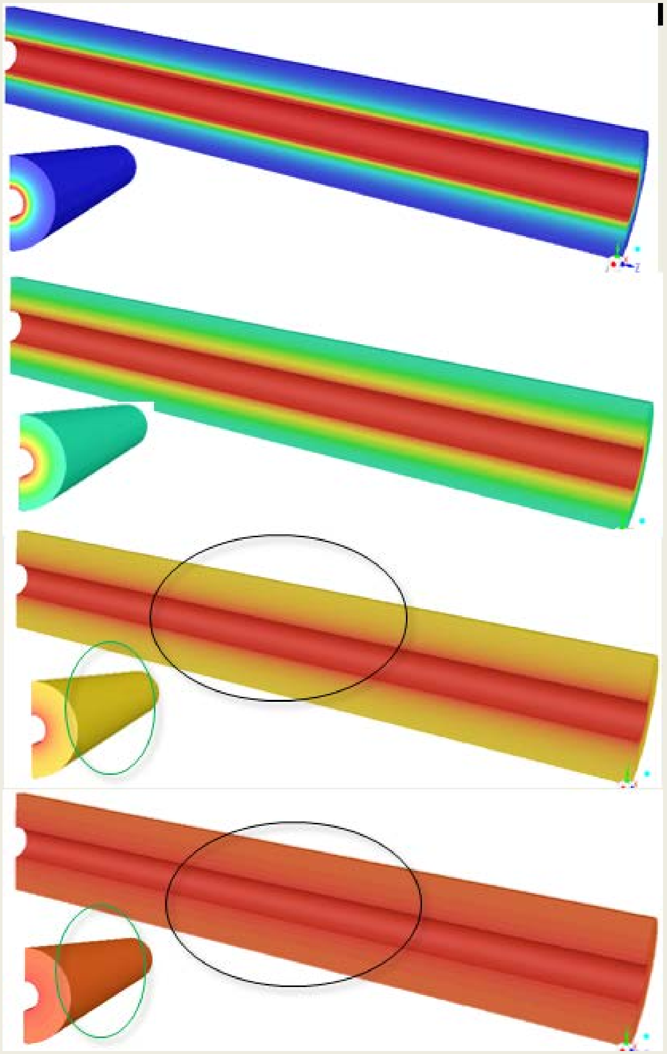
- Computational Fluid Dynamics (CFD)
- Uses propellant burn model
  - Generates propellant gas conditions
  - Drives fluid flow, heat transfer, bullet motion
  - Uses solid barrel and chamber
- Heat is input each shot with time and spatial variation
- Understanding of the differences between the test barrel and the real M240 barrel is crucial
  - Added material for IWTC mounting, and machined holes and IWTCs themselves will change behavior
  - First step is to understand the differences between the standard barrel and the modified barrel



Temperature Characterization – Numerical Methods



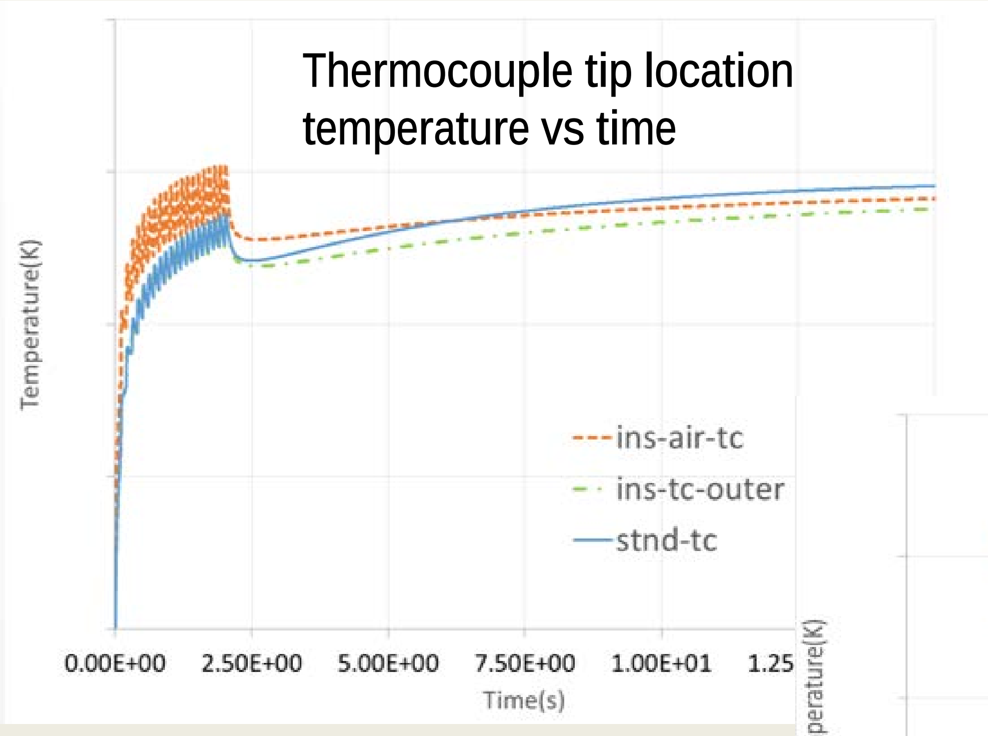
As the energy moves through the barrel over time, the cooling effect due to the additional mass of the test fixture components is more noticeable.



Temperature Test-Fixture Air Filled (ins-air)

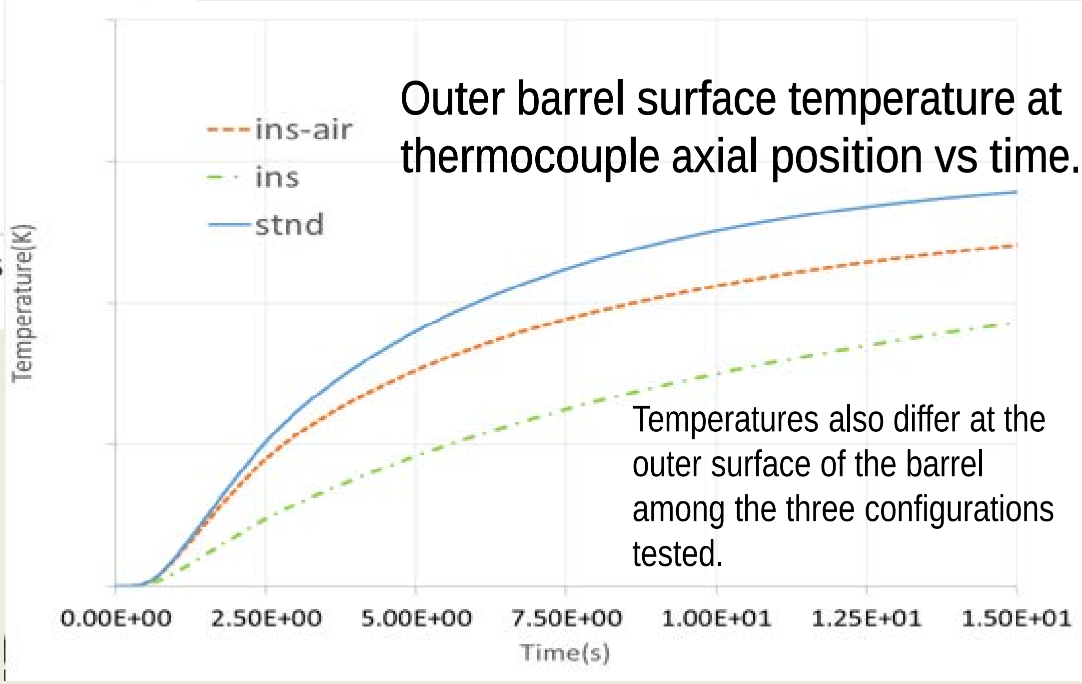
Temperature Standard(ins)

Temperature Characterization – Numerical Methods

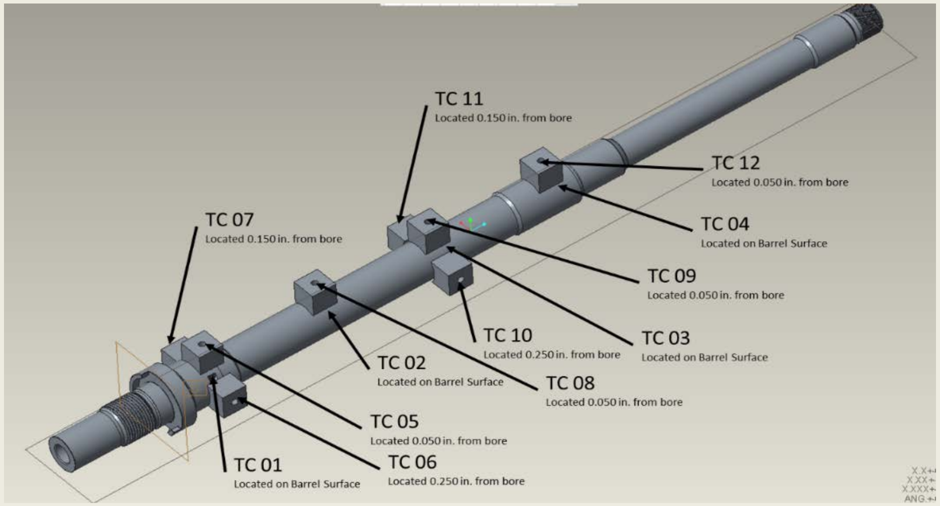


Thermocouple tip location temperature data show the differences in the peak temperatures during "firing" and then later differences in the temperatures as the heat moves through the system for the standard barrel (stnd), an air filled thermocouple geometry (ins-air) and a thermocouple geometry that is insulated(ins).

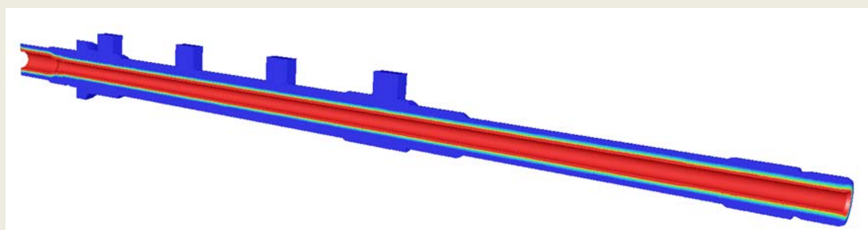
The localized effect of the test fixture geometry can also be found at the outer barrel surface, where for the time studied the temperatures for the three configurations deviate over time.

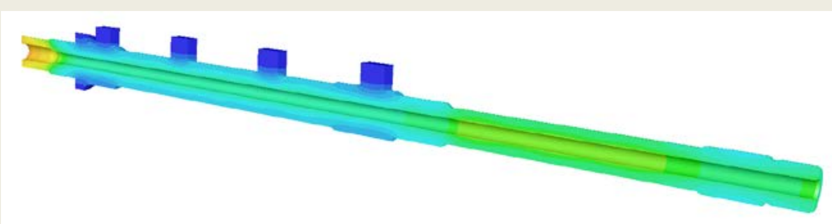


Temperature Characterization – Results



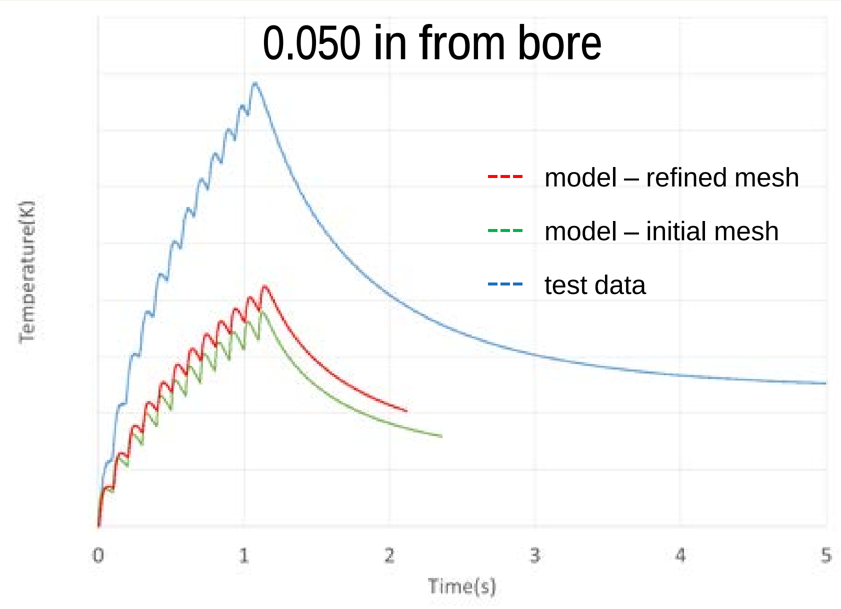
High temperature gradients develop near the bore. The gradients drop as the energy moves through more of the barrel material. The “cooling” effect as the test fixture components are heated can be seen.

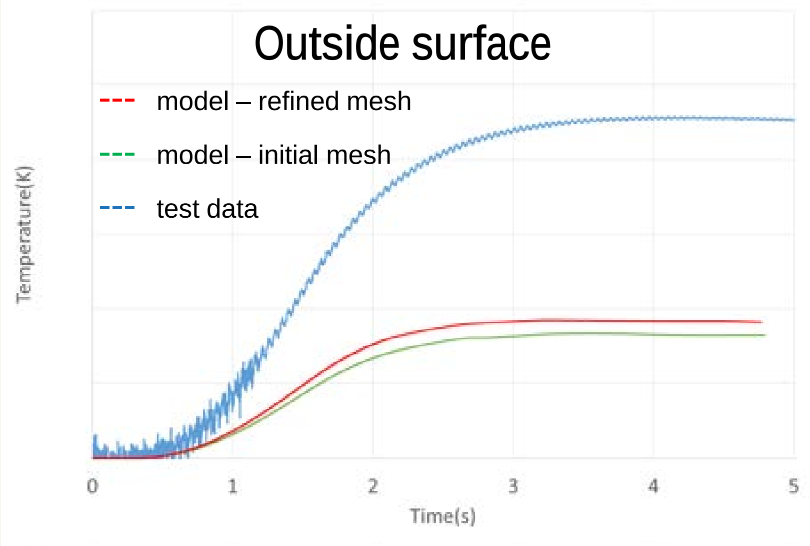


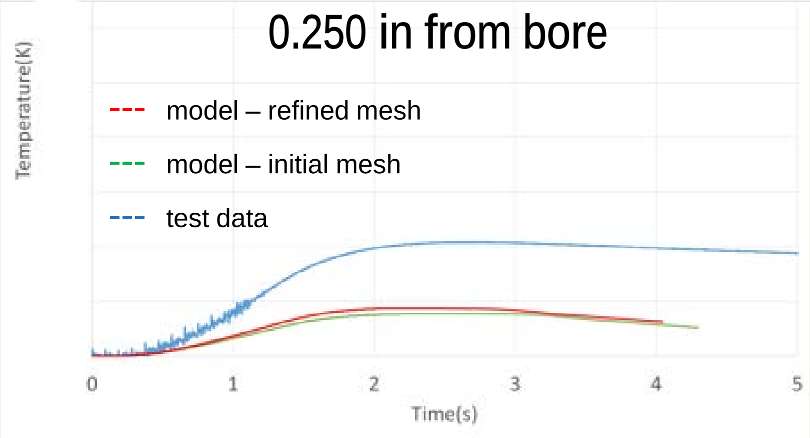


Temperature contours as one round is fired

Temperature Characterization – Results







Temperature Standard(ins)

The model and test data temperatures both show similar trends and timing of the temperature as a function of time. The test data consistently reports higher temperatures than the model results. Possible causes for this have been identified.

Temperature Characterization – Potential Reasons for Discrepancies

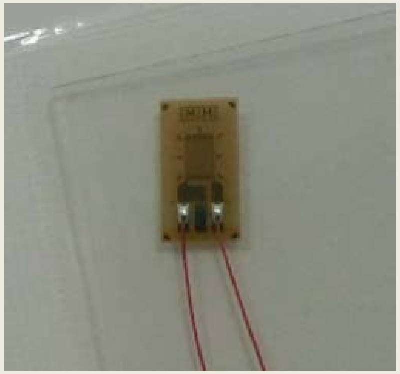
- Thermocouple components and materials are not included in the model.
- Any contact resistance between the barrel and test fixture components is neglected in the model.
- Variations in the heat input conditions between the model and the particular ammunition used in the testing may exist.
- Thermocouple tip locations may have variation from those used in the model.
- Anomalies in the thermocouple positioning or attachment may be present in the physical test system.
- The radial positioning of the thermocouple in the system with the high radial temperature gradients over a short time duration may affect the readings.
- Noise or oscillations in the measured temperatures, even at ambient, may influence readings.

Temperature Characterization – Benefits

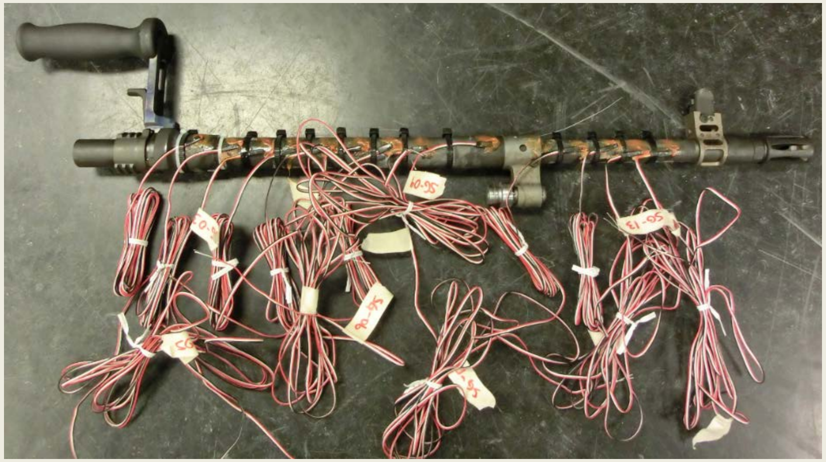
- Trends in the variation of temperatures with different radial locations can be clearly identified from both testing and numerical experiments.
- The effects of multiple rounds fired on the temperature distribution can be found from the physical testing and the numerical experiments.
- Comparisons of the data can reveal potential issues with the experimental set up: Switched wires, loose thermocouples, or different thermocouple positioning in the system.
- Models can serve as a test-bed for comparison of the thermal performance of a new design or design modification to the performance in a baseline configuration to reduce the number of physical tests that need to be conducted.

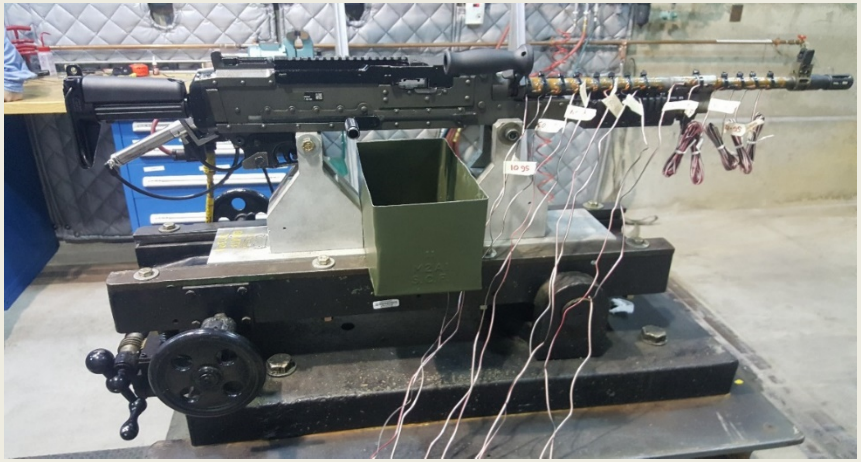
Stress/Strain Characterization – Test Methodology

- Strain gages placed at every inch down the length of the barrel
- Single axis strain gages – hoop direction only
- Sampled at 500kHz – maximum possible
- Firing scenarios
  - Single, 3rd burst, 6rd burst
- Data filtered with Keiser low pass filter and stopband frequency of 10kHz

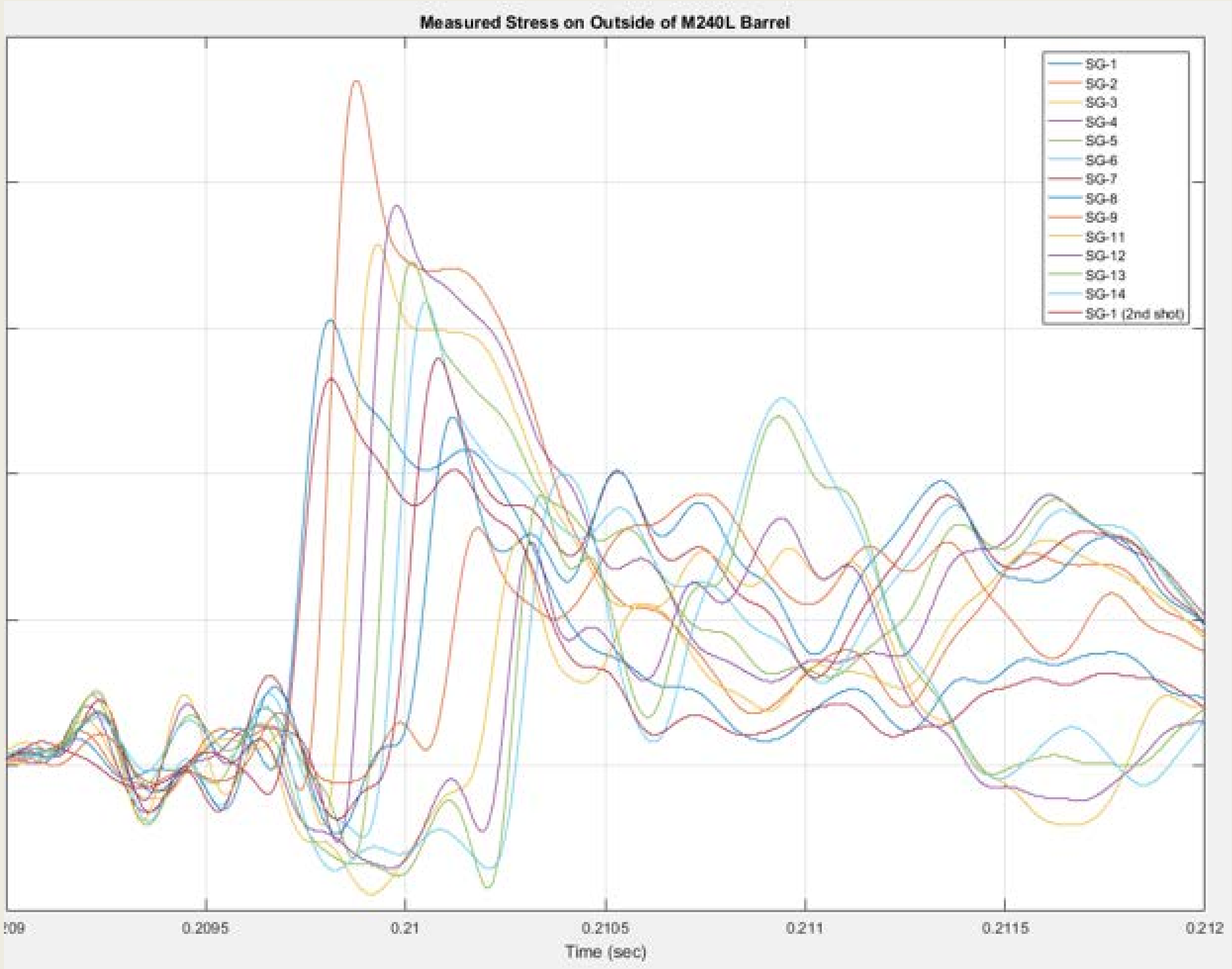


Vishay Precision Group
C2A-06-062LW-350





Stress/Strain Characterization – Test Observations

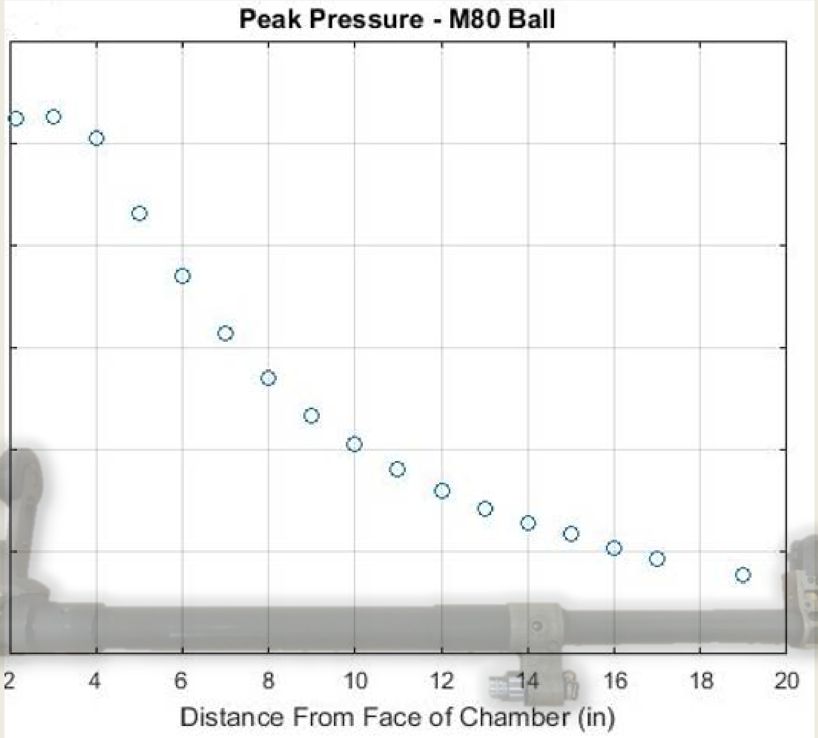


Stress/Strain Characterization – Numerical Methods

- Stress as a result of pressurization can be calculated at any point on the barrel using Lame's thick walled cylinder stress calculations, outlined in AMCP 706-252
- Tangential stress is focus for this study

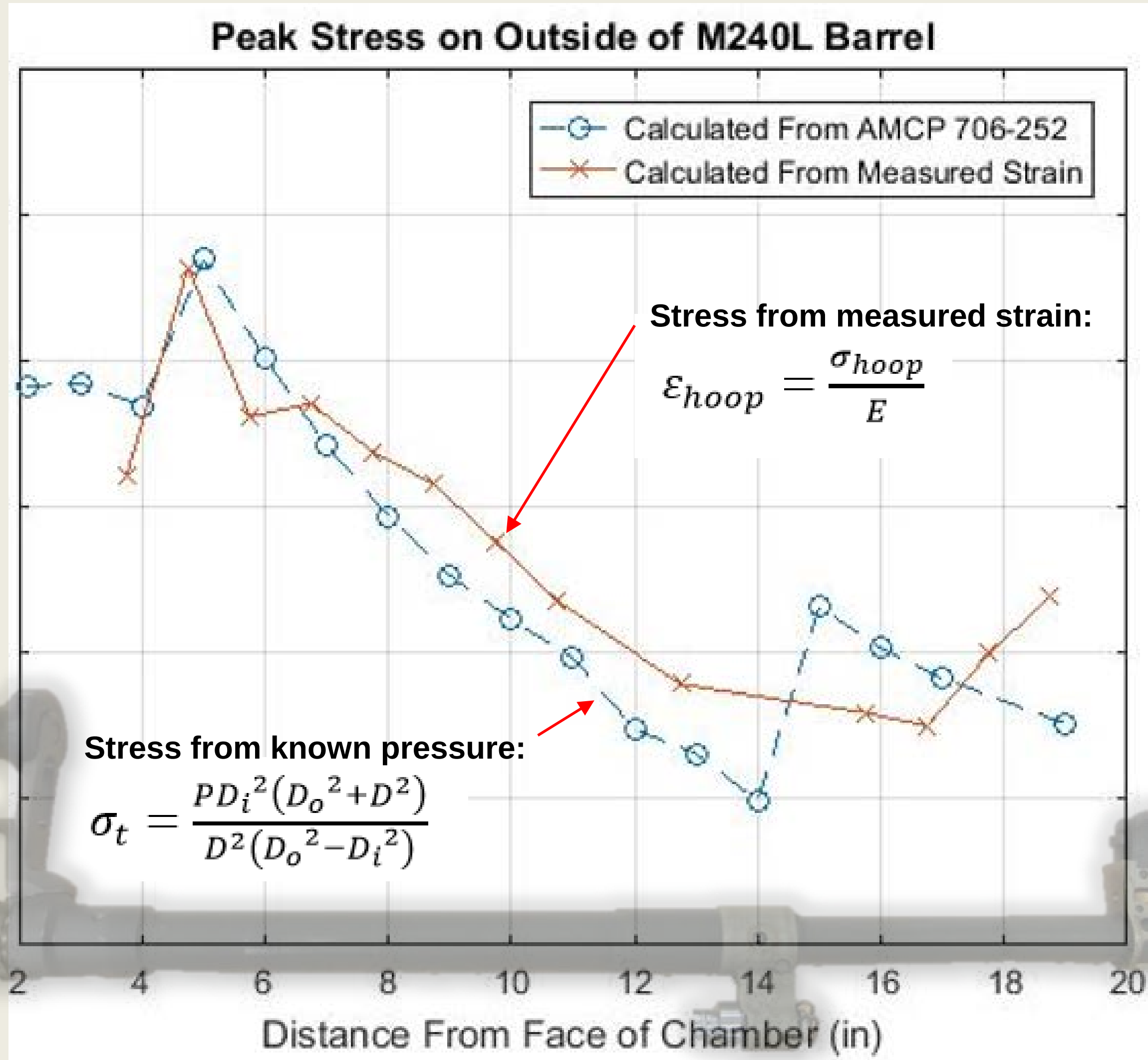
$$\sigma_t = \frac{PD_i^2(D_o^2 + D^2)}{D^2(D_o^2 - D_i^2)}$$

- AMCP 706-252[1] makes the following assumptions, which are only valid for specific cases in a machine gun barrel:
  - Elastic regime
  - Steady state, uniform temperature
- For our purposes, these are relatively valid assumptions, but for more advanced models, this would not give accurate results[2]
- Additionally, high strain rate material properties would better suit this type of analysis



[1]AMC Engineering Design Handbook: Gun Tubes, AMCP 706-252, U.S. Army Materiel Command, 1964.
[2]Chu, Shih-Chi, et al, "Gun Barrel Technology at Weapons Laboratory, Rock Island," Rock Island Arsenal, Rock Island, IL, 1968-1971.

Stress/Strain Characterization – Results



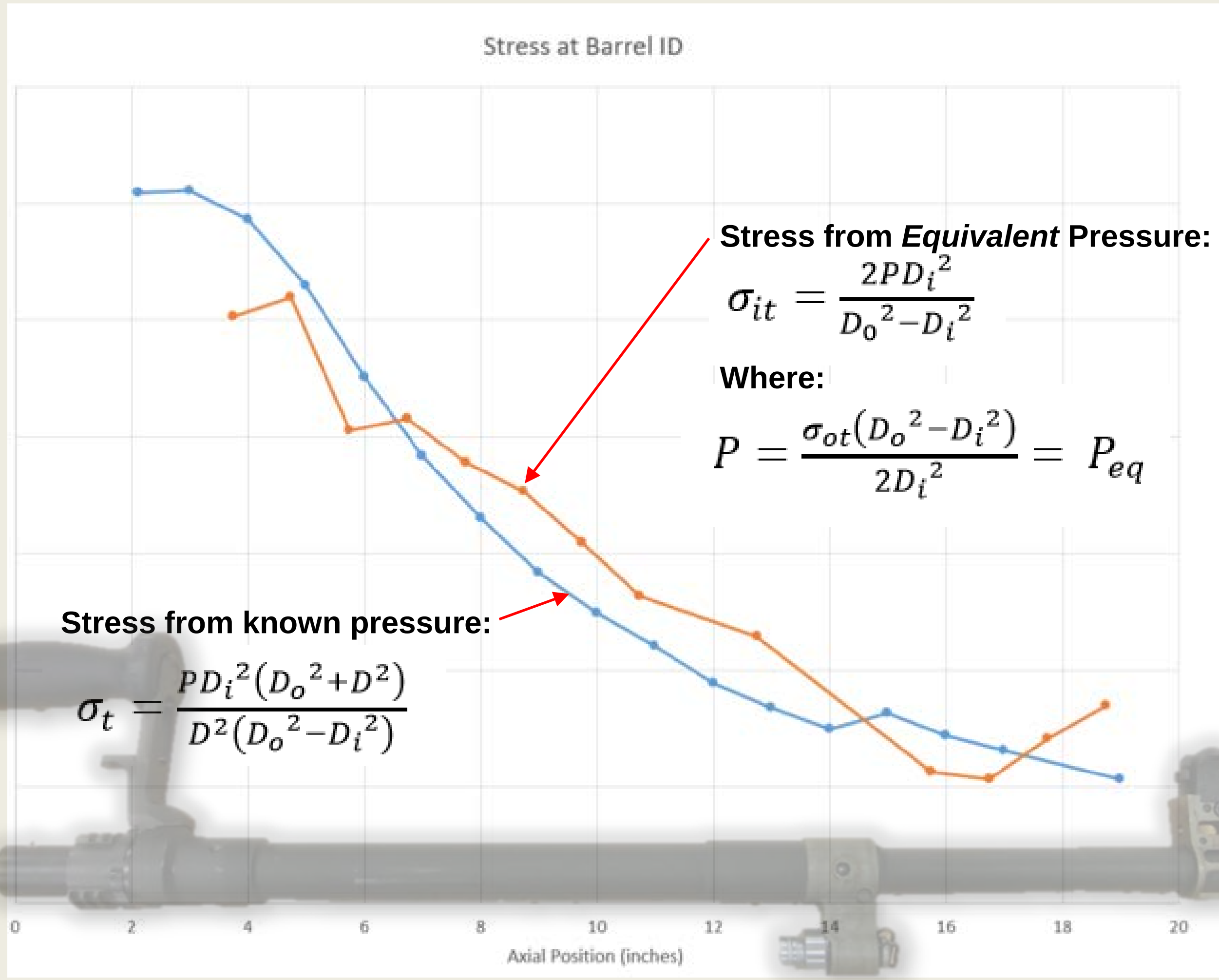
Stress from measured strain:

$$\varepsilon_{hoop} = \frac{\sigma_{hoop}}{E}$$

Stress from known pressure:

$$\sigma_t = \frac{P D_i^2 (D_o^2 + D^2)}{D^2 (D_o^2 - D_i^2)}$$

Stress/Strain Characterization – Results



Stress from *Equivalent* Pressure:

$$\sigma_{it} = \frac{2PD_i^2}{D_o^2 - D_i^2}$$

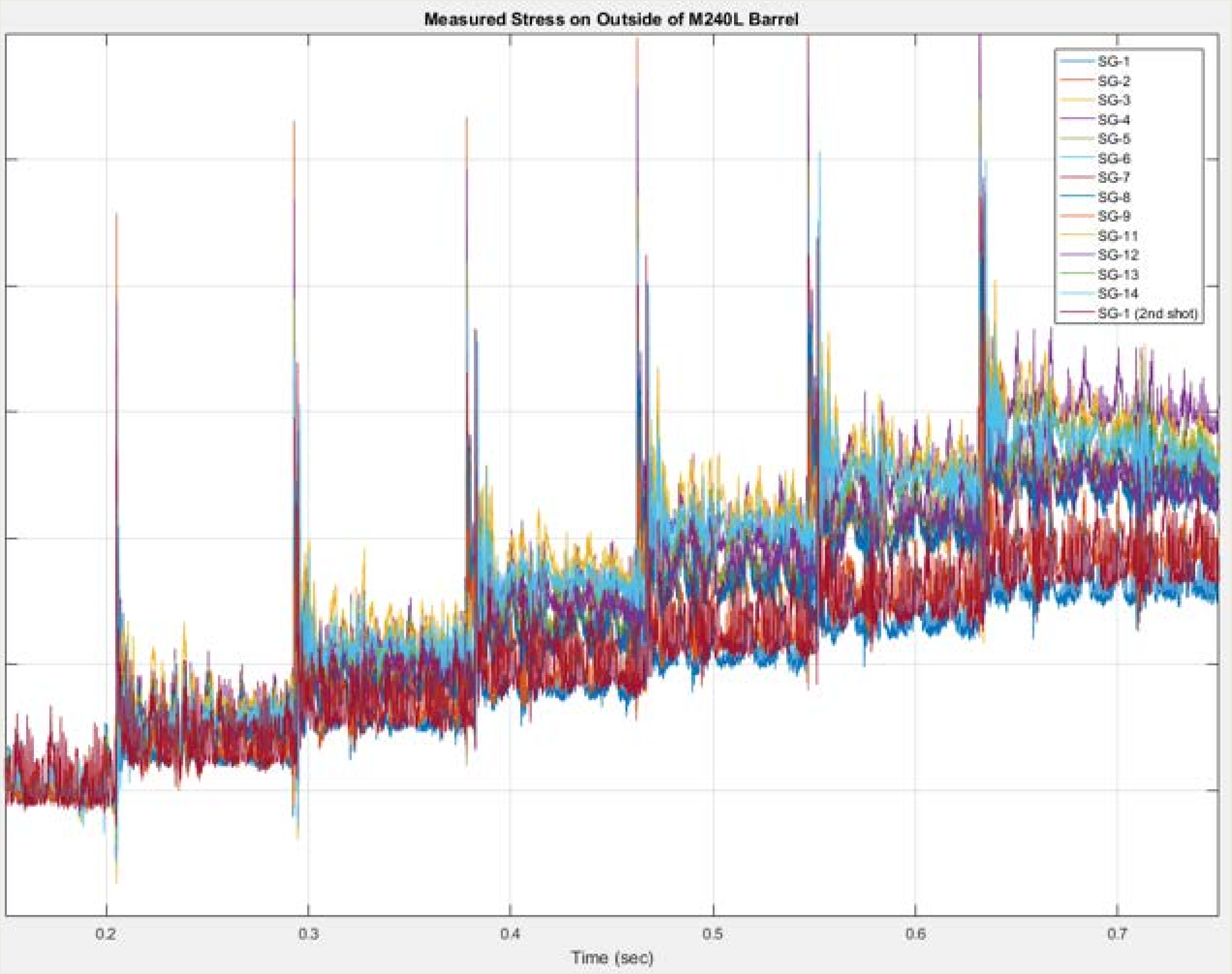
Where:

$$P = \frac{\sigma_{ot}(D_o^2 - D_i^2)}{2D_i^2} = P_{eq}$$

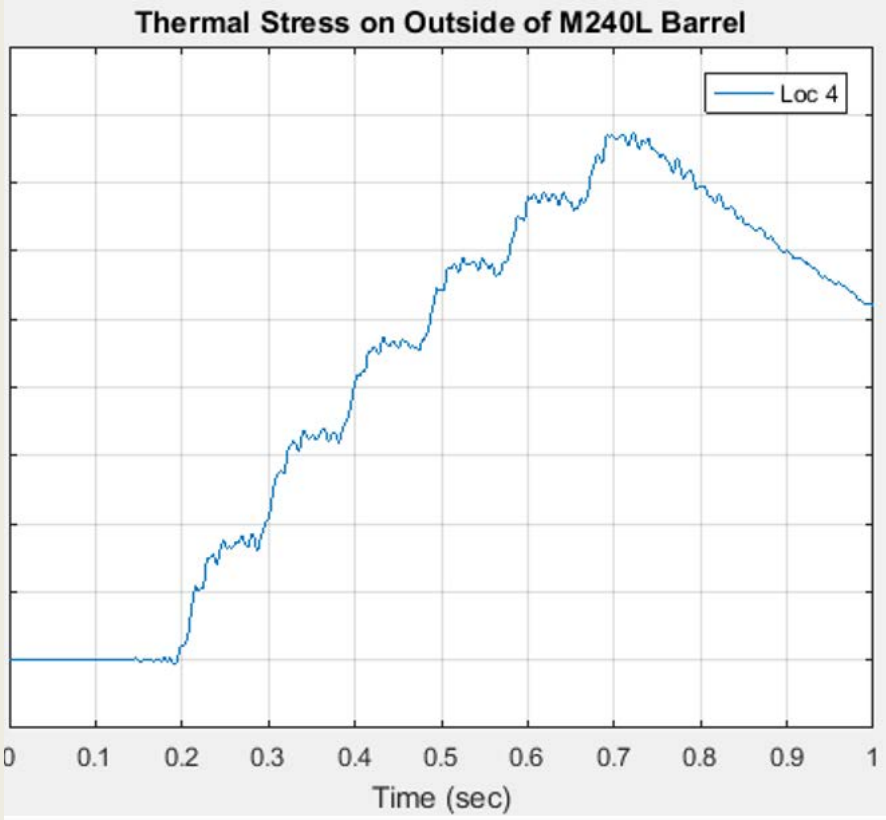
Stress from known pressure:

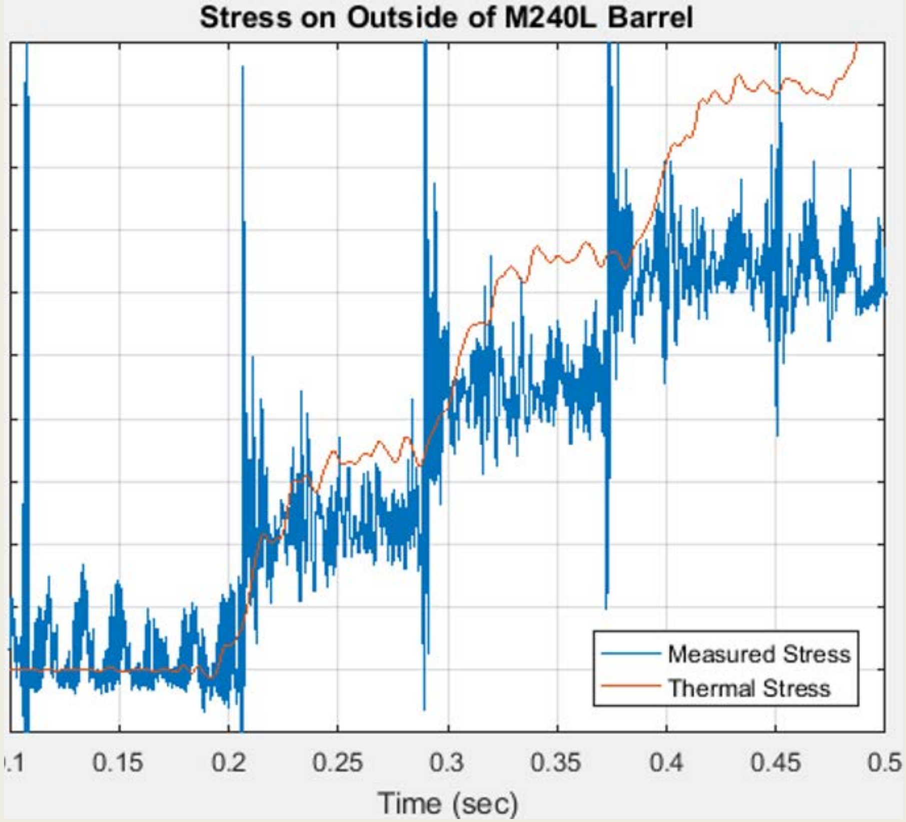
$$\sigma_t = \frac{PD_i^2(D_o^2 + D^2)}{D^2(D_o^2 - D_i^2)}$$

Stress/Strain Characterization – Thermal Stress



Stress/Strain Characterization – Thermal Stress





Conclusions, Takeaways, and Recommendations

Thermal Characterization

- IWTCs are powerful tools, but do have some drawbacks
- Possibly look at other measurement methods
- CFD models and test data showed good correlation in timing of events, but the overall temperature increase showed larger differences
- There are a variety of reasons for the differences between test and models
- More research is recommended to find the sources of differences, and show better correlation between test and modeling
- Models can serve as a test-bed for comparison of the thermal performance of a new design or design modification to the performance in a baseline config. to reduce the number of physical tests that need to be conducted.

Stress/Strain Characterization

- There are no known methods to measure strain at the bore surface
- Future testing should experiment with the use of multi-axis, high temperature strain gages
- Methods to calculate strain at the outside of the barrel using the AMCP 706-252 correlate well with test data, assuming steady state and elastic regime
- Elastoplastic theory should be further studied for more advance solutions
- Advanced FEA methods that account for elastoplasticity, temperature dependent material properties, and high strain rate material properties should be pursued
- Thermal stress is measured and shows general correlation to calculations, but more advanced methods that account for non-linearity should be pursued

Questions

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