US ARMY RDECOM

U.S. Army Research, Development and Engineering Command

Malcolm Baldrige National Quality Award

2007 Award Recipient

ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER PICATINNY ARSENAL, NJ

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

One-Way Luminescence (OWL) Technical Achievements

NDIA 26-28 April, 2016

Presenters:

Matt Horch – APO, OWL

Will Battistelli – Project Engineer, OWL

Mike Pagonis – Test Engineer, OWL

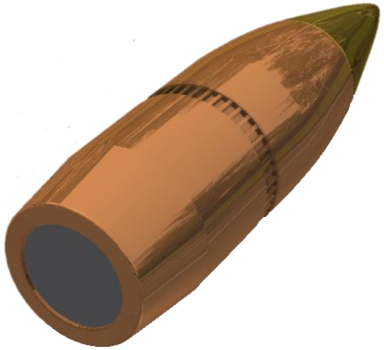
Jeff Krug – ARDEC AETD

Heather Pacella – ARDEC AETD

Agenda

- OWL Overview (M. Horch)
- Testing Standardization (W. Battistelli)
- Projectile Heating Study (J. Krug & M. Pagonis)
- Projectile Heating Analysis (H. Pacella)
- OWL Program Schedule
- Program Conclusion and Path Forward
- Acknowledgements
- Questions

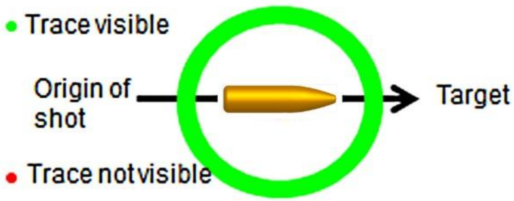
OWL focuses on integrating a one-way visible, full day/night tracer to improve Warfighter capability, reduce logistical burden, and reduce ammunition cost.



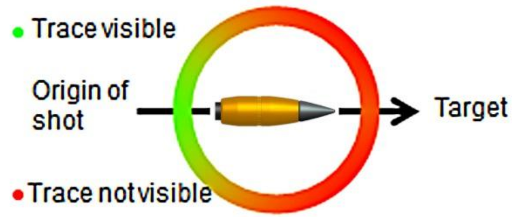
OWL Overview
Introduction

Visual Signature Comparison

Current Tracer

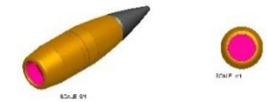


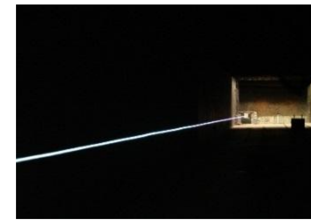
Visual Signature with Current Tracers



Approximate Visual Signature with One Way Luminescent Tracers

LOT/OWL Concept





Operational/Training

- **Increases soldier's survivability**
  - Substantially reduces signature of tracer
- **Greater lethality for belted ammunition**
  - Tracer round gains lethality component
- **Trajectory Matching for ball and tracer rounds**
  - Minimal material exiting the round
- **Potential elimination of range fires due to tracers**
  - Training uptime increased
- **Potential for every round to trace**

Operational/Training

- **Potential increase in soldier aim/effectiveness**
  - Faster point of aim corrections
  - Follow every round to impact
- **Potential addition of a new capability to rifle/carbine weapon systems**
- **Potential elimination of night vision equipment white-out**
  - No traditional pyrotechnic causing intense signature

Overarching goal of OWL is to Integrate a non-pyrotechnic, one-way visible, full day/night tracer into current ammunition production products in order to improve warfighter capability, reduce logistical burden, and reduce ammunition cost.

OWL Overview
Technology List
Competing OWL Concepts

Environment	No Launch	Controlled Launch	Launch under Stress	Current Assessment
System	**Down Selected Out**	**Projectile/Cartridge – Mann Barrel Testing**	**Projectile Testing – Current Weapons System**	
	TRL 3	**TRL 4**	**TRL 5/6**	
Tested Technologies		**OWL-E** Assessed 20-21 April 2015	Plan 3rd QTR FY17	Visible to >815m @ twilight; 600m-700m @ day, naked eye
		OWL-L Assessed 21-22 Oct	Final Test 4th QTR FY16	Visible to 100m indoor tunnel naked eye
	Industry DOTC Efforts	**Industry DOTC Efforts**		Various development efforts at different stages of development
	Phosphor/Nano-Phosphor	**Will not meet full day/night OWL requirements**		Visible to ~450m with night vision equipment (NVE), will not meet day time requirements
	Thermo-Luminescent Decay Materials			Visible to ~ 100m tunnel with NVE, additional material required to initiate reaction
	Phosphor w/ Coating			No additional benefit from coating materials to increase excitation
	Various Thin Film Energetic Materials			Multiple configurations: trouble initiating, propagating reaction, low overall brightness, or maintaining reaction time
	Reflective Materials			Visible to 600m @ night naked eye, required bright light source for visibility
	Chemi-Luminescence			Could not initiate reaction in required time for visibility during flight & packaging too big

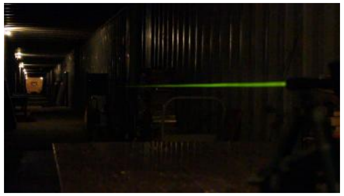
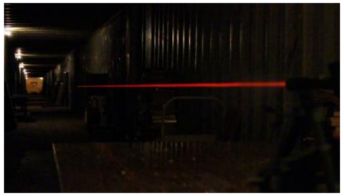
USG Technologies
Awarded Industry Technologies

OWL Overview
Technology List
Failed Concepts

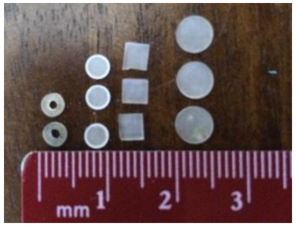
Fired Concepts

Phosphor

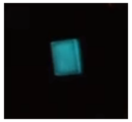
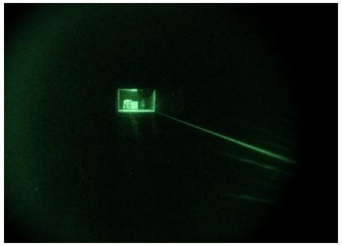


Thermo Luminescent Decay





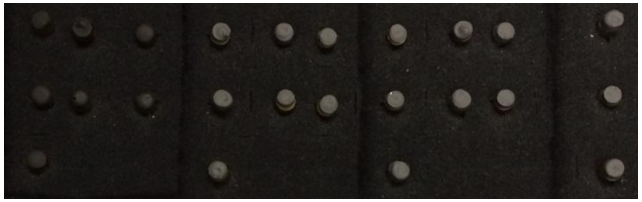



Reflectance



Lab Tested Concepts

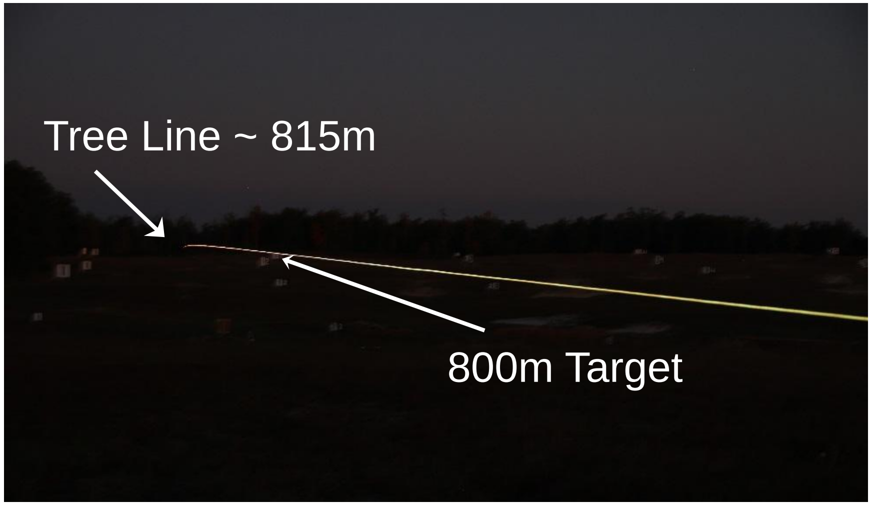
Thin Film Energetic



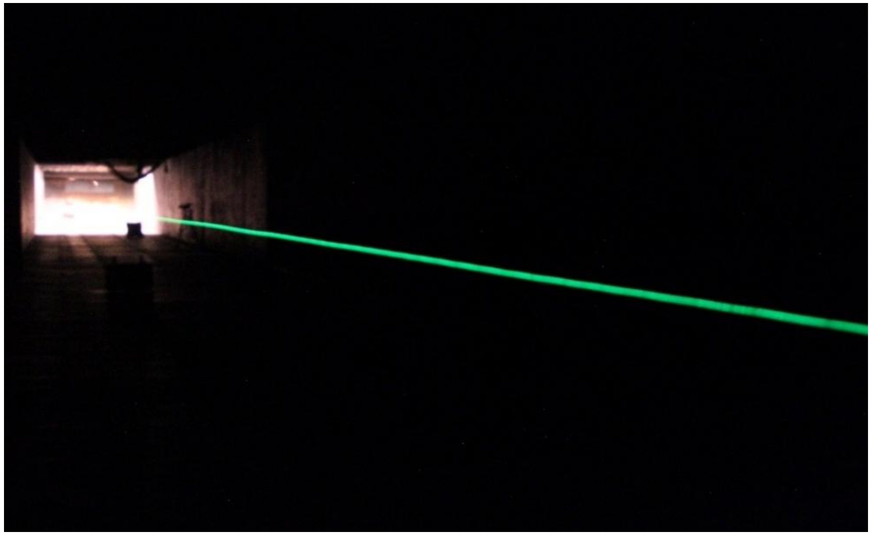
Phosphor with Coating

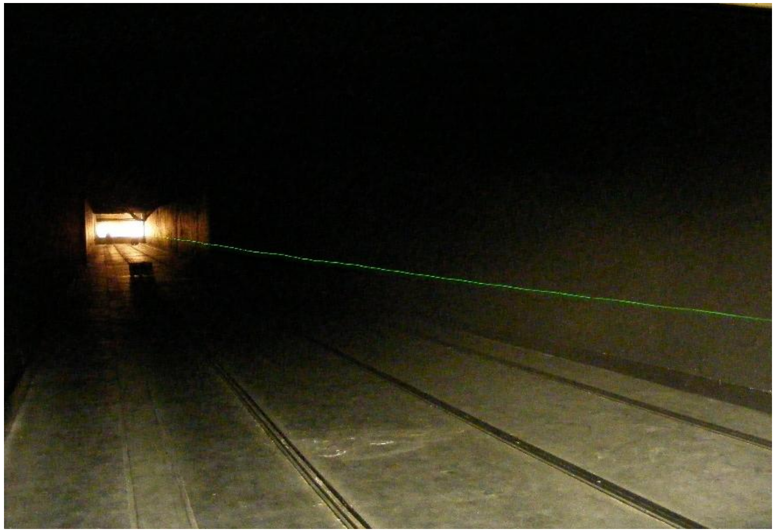
Chemi-Luminescent Technology

Testing Standardization
OWL Testing Successes
OWL-E



Testing Standardization
OWL Testing Successes
OWL-L





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Testing Standardization
Path Forward

- OWL has been under development for the past 4 years
  - Technologies investigated are vastly different than traditional M62 tracer
  - Significant benefits by exploring new novel technologies
    - Minimizing tracer material
    - Adjustments to visibility angles to increase Soldier survivability
- USG has explored multiple technologies to meet Warfighter requirements
  - Technology exploration has been expanded to Industry
- USG has begun developing test standards as well as unique analysis tools that are required by the development of OWL technologies in anticipation of the next program phase
- Technology development phases are coming to an end, with USG planning to enter into EMD Acquisition phase at the beginning of FY18

Testing Standardization
Novel Testing Methods

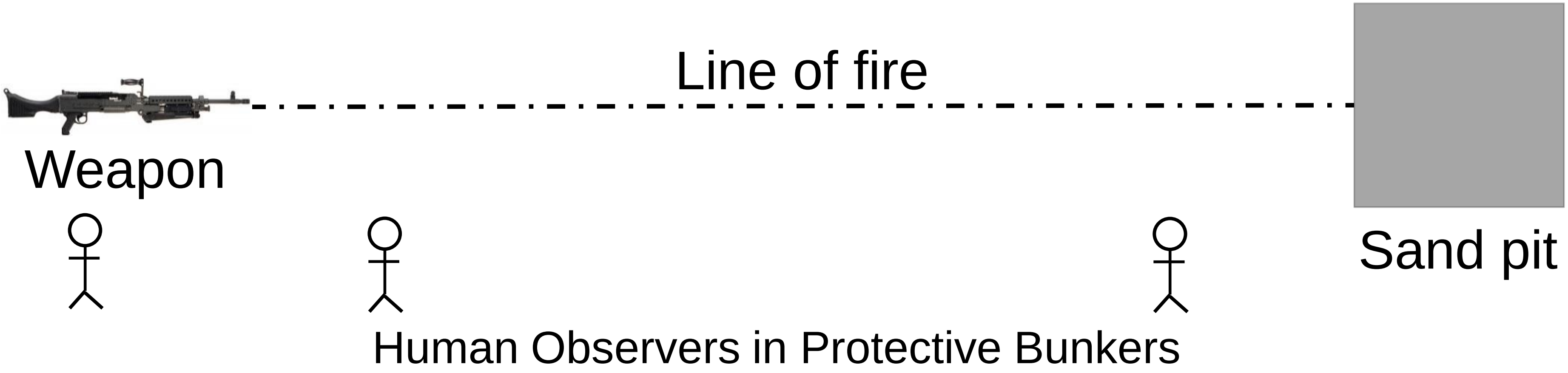
- OWL Tracer Testing Issue
- Current Production Pyrotechnic Tracer Test Method
- Video Camera Issues
- “Streak” Camera Testing
- Detector of OWL Munitions (DoOM)
- Path Forward

Testing Standardization
OWL Tracer Testing Issue

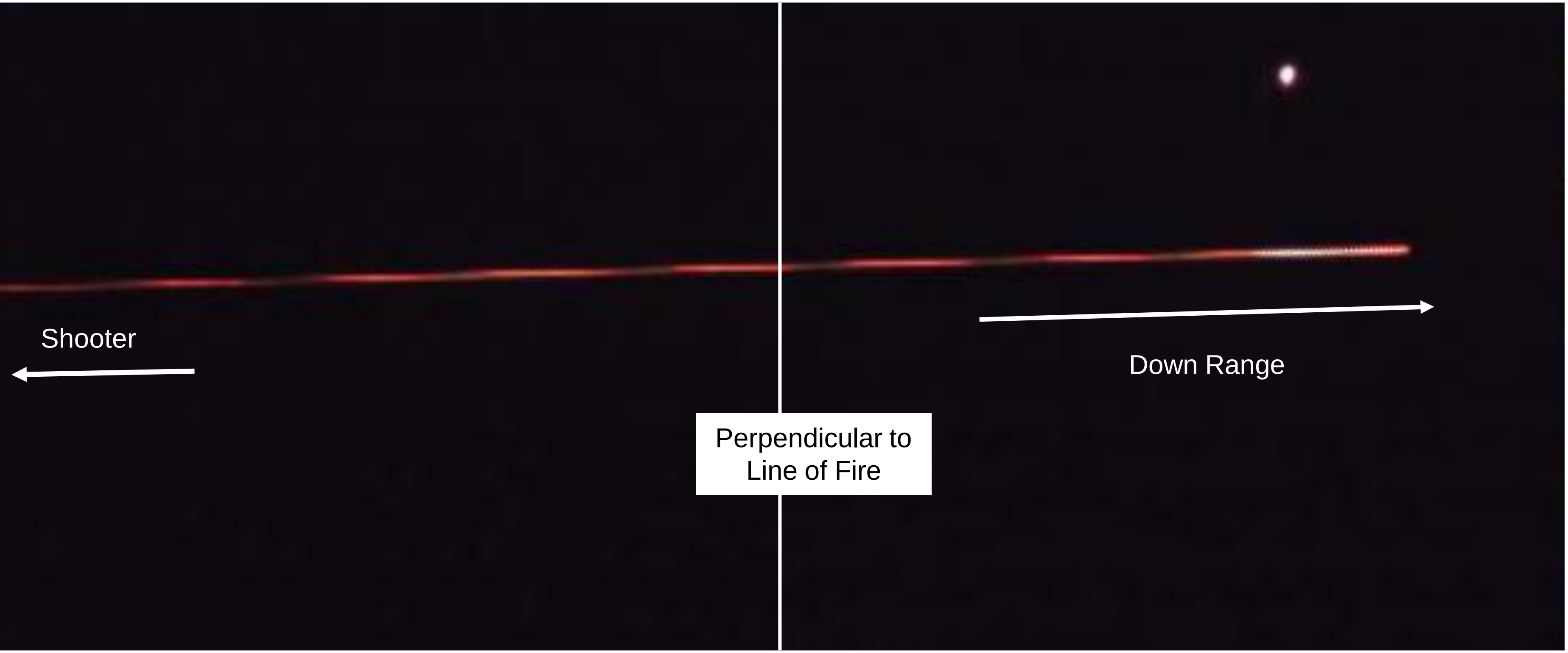
- Tracer Visibility
  - Legacy pyrotechnic tracers are 360° viewable
  - By design, OWL is not 360° viewable
- Due to this feature of OWL, the current testing method will not work

Testing Standardization
Current Production Pyrotechnic Tracer Test Method

- Observer bunkers located multiple distances downrange
  - 90° perpendicular to the line of fire
  - Approx. 75 yards away from the line of fire
- Human observers score trace as:
  - Blind Trace: No trace signature when supposed to be at full luminosity
  - Early Trace: full luminosity when supposed to be either dim or invisible
  - Dim Trace: visible, but not tracing at full luminosity



Testing Standardization
Current Production Pyrotechnic Tracer Test Method



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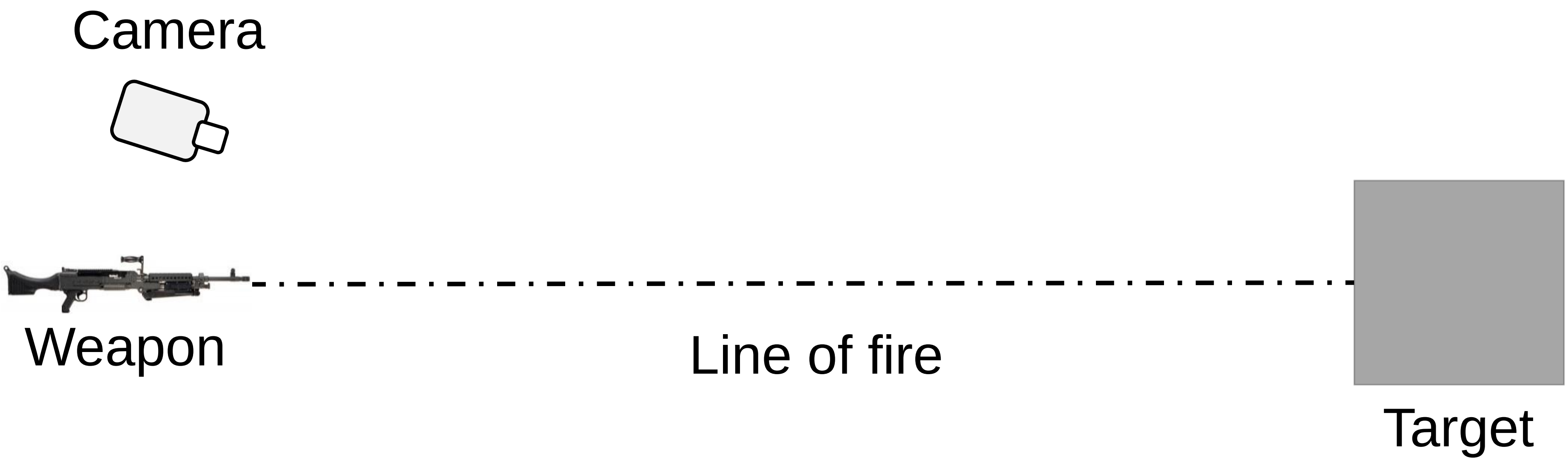
Testing Standardization
Video Camera Issues

- Video camera and naked eye see different things
- Video camera live feed gets close
- Detail gets lost during recording (even at 60 fps)

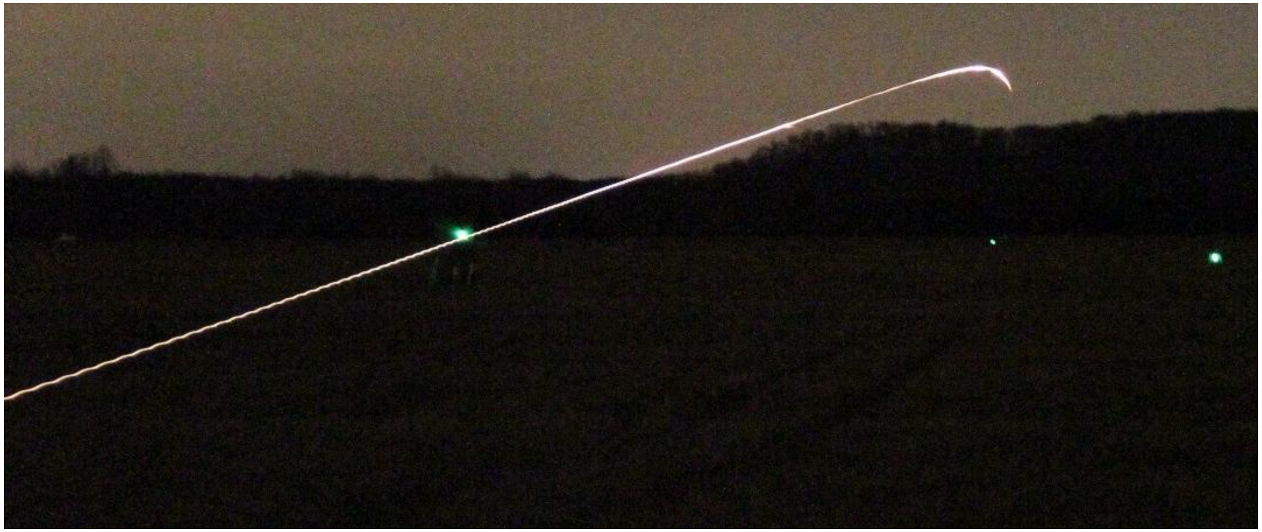
Testing Standardization
"Streak" Camera Testing

- Long Exposure Still Picture taken from shooter location
  - Canon EOS7D DSLR camera used



Testing Standardization
"Streak" Camera Testing - OWL

Testing Standardization “Streak” Camera Testing – Legacy Vs OWL



Testing Standardization
Detector of OWL Munitions (DoOM)

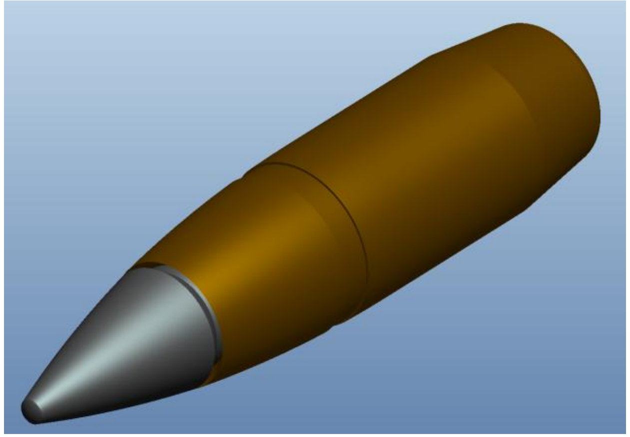
- Basics:
  - Detectors used to view the trace instead of human observers
  - Relays signal back to a computer for processing
- Benefits
  - Will work for both OWL and current Legacy Tracers
  - Feasible during various outdoor lighting conditions
  - Eliminates subjectivity of human observers

Testing Standardization
Path Forward

- DoOM is the preferred concept for future testing
  - Will work for both OWL and current Legacy Tracers
  - Feasible during various outdoor lighting conditions
  - Eliminates subjectivity of human observers
- Streak cameras to be used for developmental testing

Projectile Heating Study
Modeling & Simulation Overview

- Modeling & Simulation (M&S)
  - Models – CAD, mathematical
    - 3-dimensional
      - half-symmetry/quarter-symmetry
    - 2-dimensional
      - usually axisymmetric/periodic

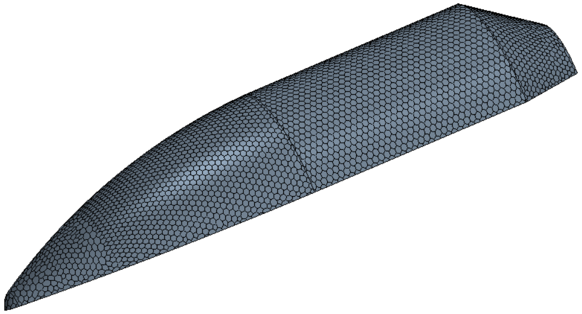


3D representation, 7.62 mm projectile (Pro/E)

  - Simulation – represents the physics of a system without actually testing

PDE → Algebraic

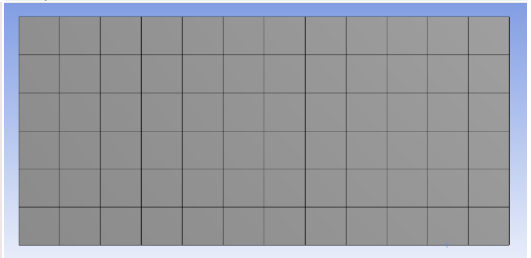
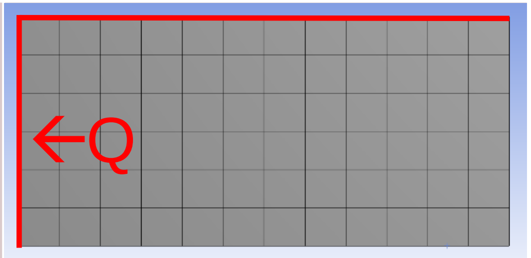
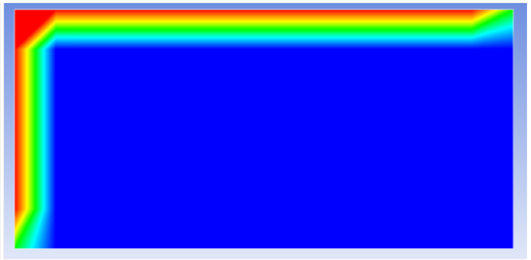
$$\frac{\partial T}{\partial x} \approx \frac{\Delta T}{\Delta x}$$



mesh for finite element analysis

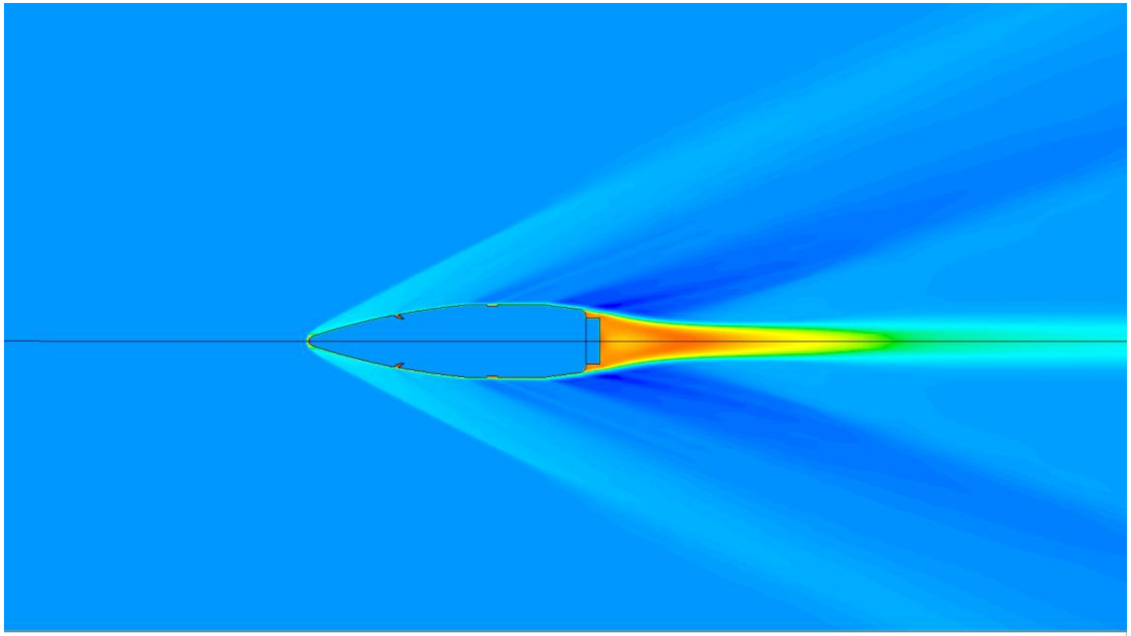
    - FEA – Finite Element Analysis (structural)
    - FVM – Finite Volume Method (fluids)
    - FDM – Finite Difference Method (heat transfer)

Projectile Heating Study
M&S Workflow

M&S Step	Description	Example
1. Domain Creation	• Structural (physical parts) • Fluid (control volume)	
2. Mesh	• Discretize domain • Refine areas of interest	
3. Physics and Conditions	• Define physics • Apply initial and boundary conditions	
4. Post-Process	• Analyze results • Rerun as necessary	

Projectile Heating Study
Previous Modeling Efforts
(Video)

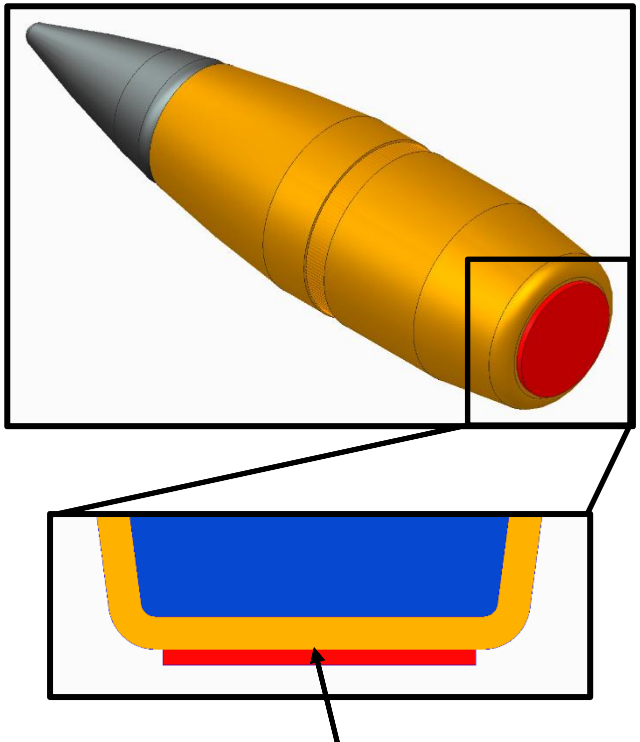
- Conjugate heat transfer (CHT) analyses of various OWL components
  - CHT modeling refers to simulation temperature flow between solids and fluids
    - Primarily conduction in solids and convection in fluids



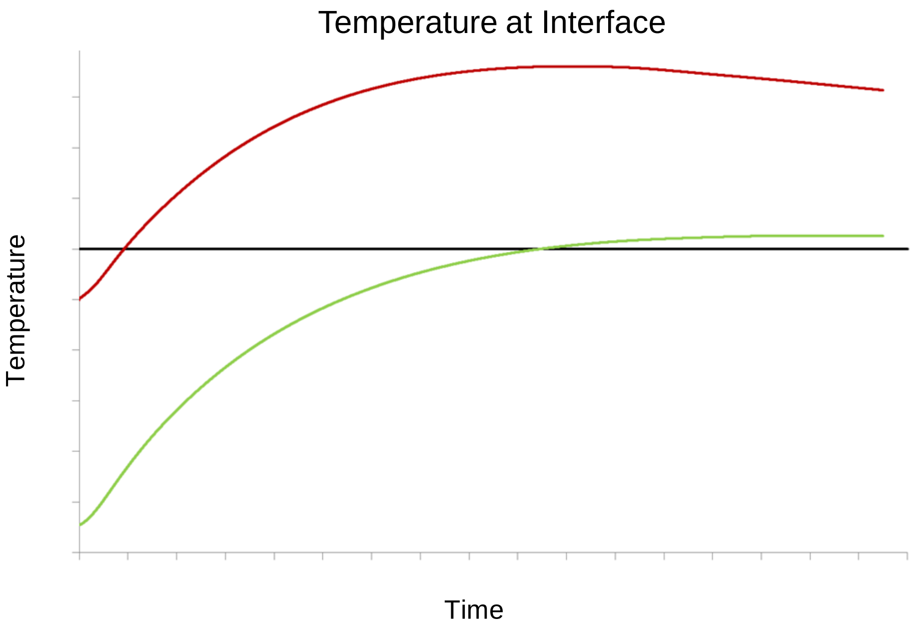
- Examples of CHT: heat exchangers in chemical plants, processor heat sinks, and projectile heating (seen above)

Projectile Heating Study
Previous Modeling Efforts
Tracer Prototype 1

Assumption: in-bore heating effects are negligible.

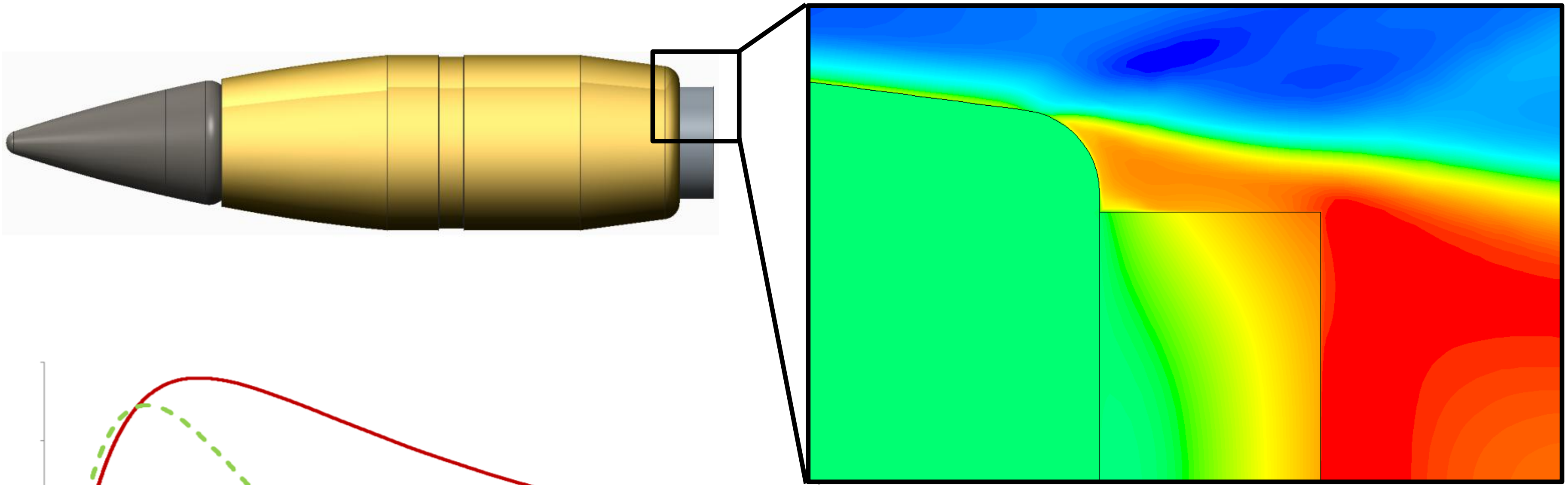


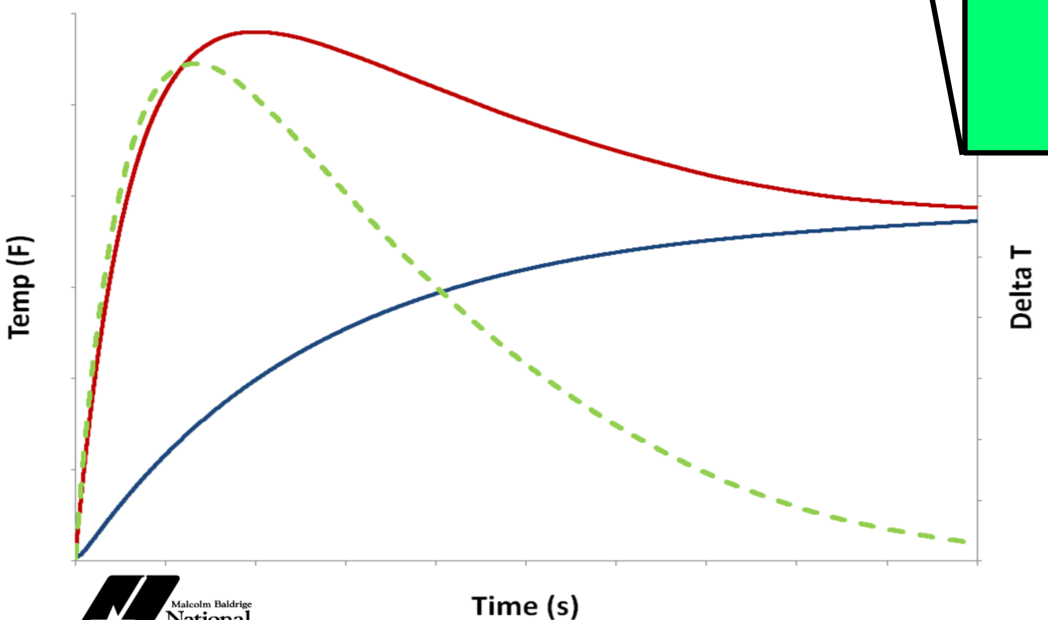
Determine the maximum temperature seen here during flight of the projectile



Modeling showed that the safe limit of the adhesive would be exceeded when firing in both initially ambient as well as hot environments. Subsequent analyses led to the selection of an appropriate adhesive.

Assumption: in-bore heating effects are negligible.

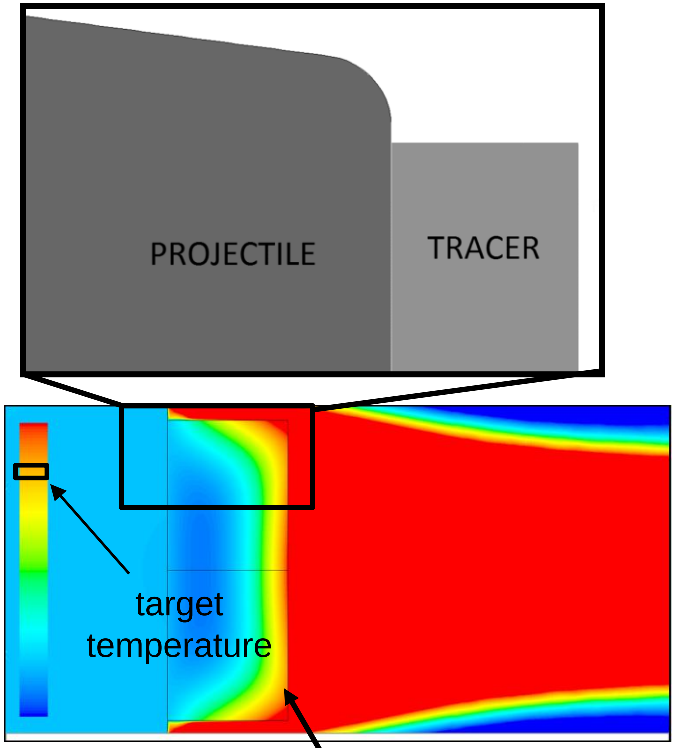


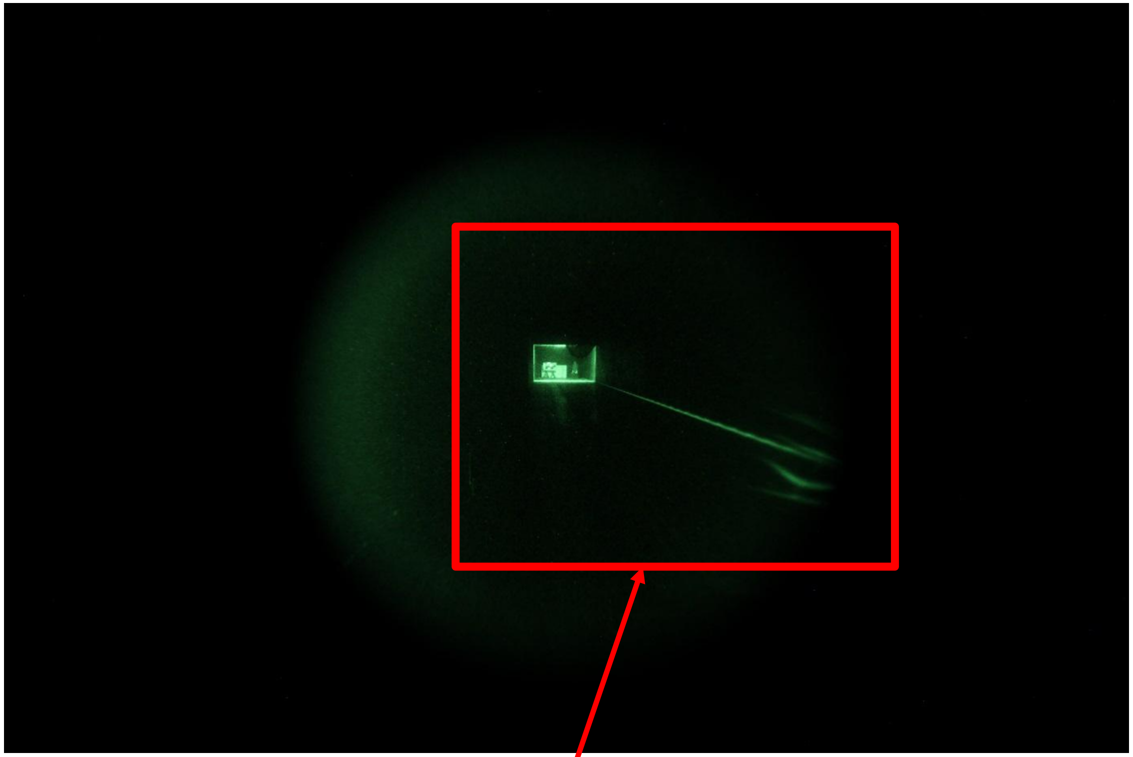


Modeling showed that the temperature delta would not be high enough throughout the flight.

Projectile Heating Study
Previous Modeling Efforts
Tracer Prototype 2

Assumption: in-bore heating effects are negligible.





Modeling showed little to no luminescence in the tracer

During testing, luminescence was not only achieved right out of the barrel, but for a much longer duration

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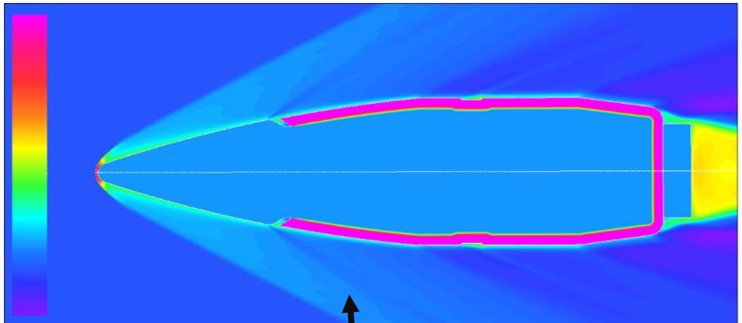
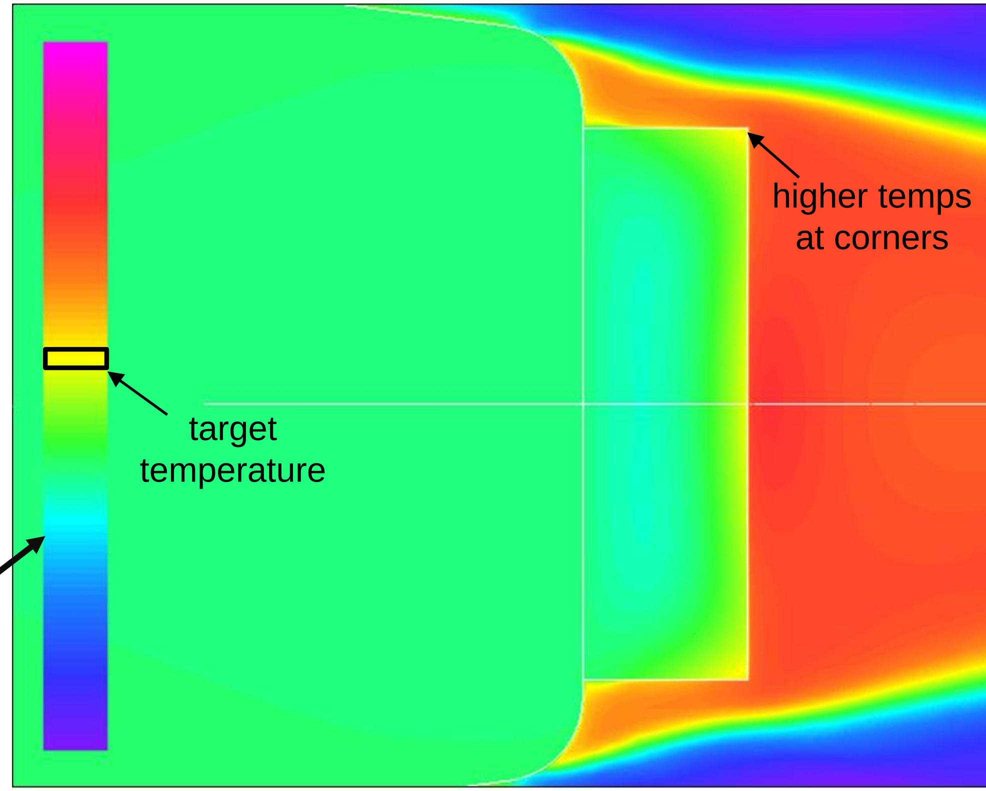
Projectile Heating Study
In-bore simulations

~~**Assumption: in-bore heating effects are negligible.**~~



Increased jacket temperature to simulate barrel heating

Though the jacket temperature was drastically increased, the tracer still did not reach the temperatures required to glow



Modeling the interior ballistic pressures, temperatures, and chemical reactions would be time intensive and computationally expensive. Testing for empirical data would be required.

Projectile Heating Study
Motivation

- **Why**
  - No specific temperature data for a 7.62mm projectile exiting a barrel
  - Test collected surface temperatures of projectiles exiting gun barrels to capture internal heat transfer due to in-bore conditions
    - 7.62mm projectiles are used in many weapon systems
    - Data was captured for wide range of barrel lengths: 8 in to 24 in
  - Data will be used as an initial condition to the conjugate heat transfer analyses
    - Increase fidelity of current and future models

- **Goal**
  - Represent the in-bore heat transfer of a projectile immediately before it enters free flight
  - Model will be used to help determine a minimum temperature requirement for potential tracer materials
    - Initial model will be used throughout small caliber munitions
    - Used on legacy and future small caliber concepts

Projectile Heating Study
Test Setup Schematic

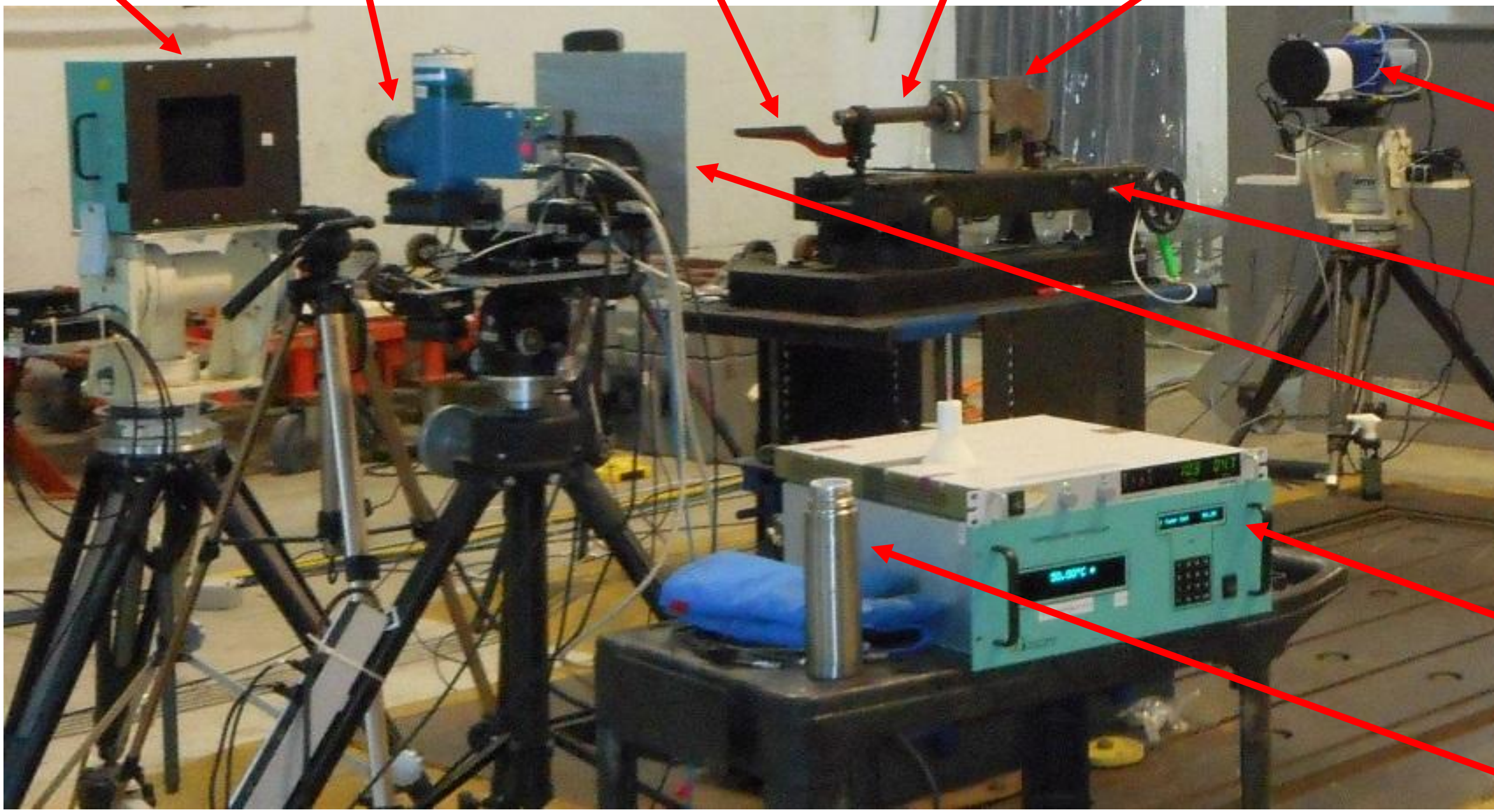
Black Body

Thermal Highspeed Midwave IR Camera

Magnetic Chronograph

Modified Barrel

Universal Receiver



Thermal Highspeed Longwave IR Camera

Table Mount

Gas Shield

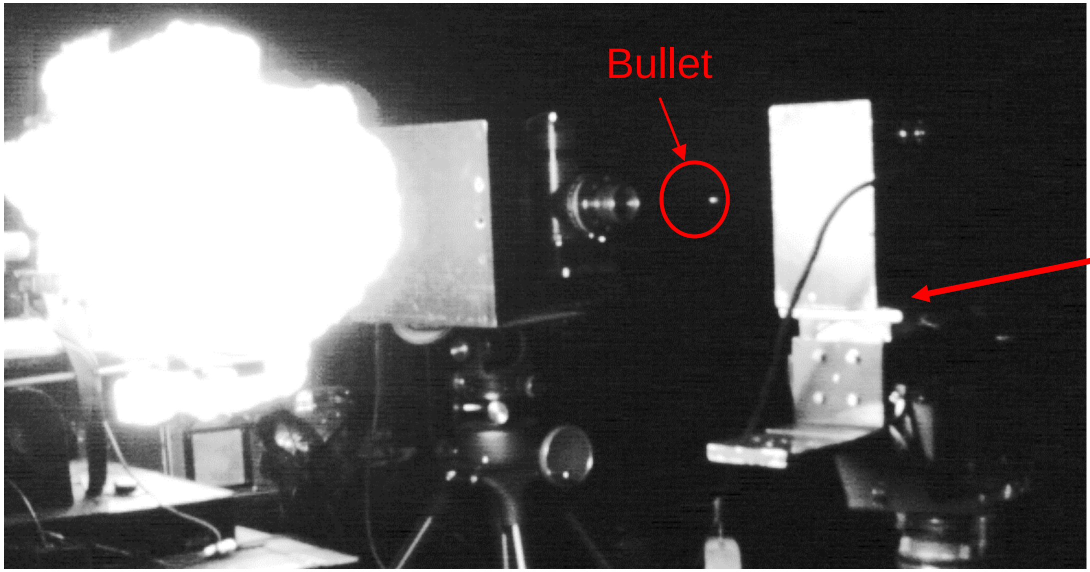
Black Body Temp Controller

Liquid Nitrogen

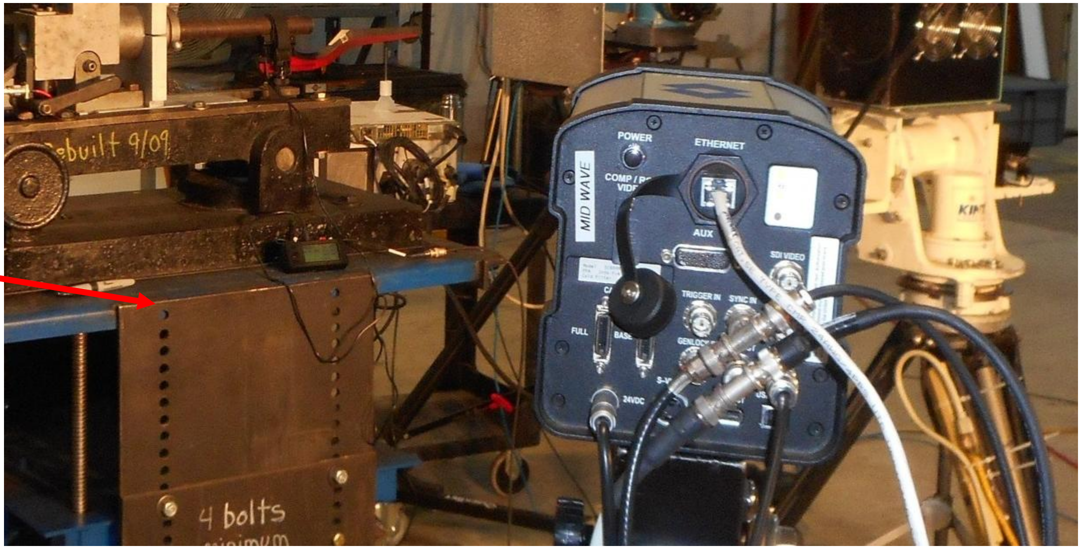
Projectile Heating Study
Bullet Capture

- Gunner pulled trigger (timing synced with clock)
- Magnetic chronograph with specialized software calculated bullet velocity
- Pulse sent to cameras triggering the capture event
  - When the bullet was in the field of view (3in window)
- A signal generator was used to continuously trigger cameras at 10Hz before and after bullet was fired to reduce file size
  - Signal generator was synchronized to be out of phase with the gunner so that the chronograph wouldn't trigger the cameras too early or too late (timing was essential)
  - Only captured the bullet at one moment and not continuously
- Kept the magnetic chronograph 36in from the camera
  - Consistent timing
  - Greatly increased repeatability

Projectile Heating Study
Event Picture



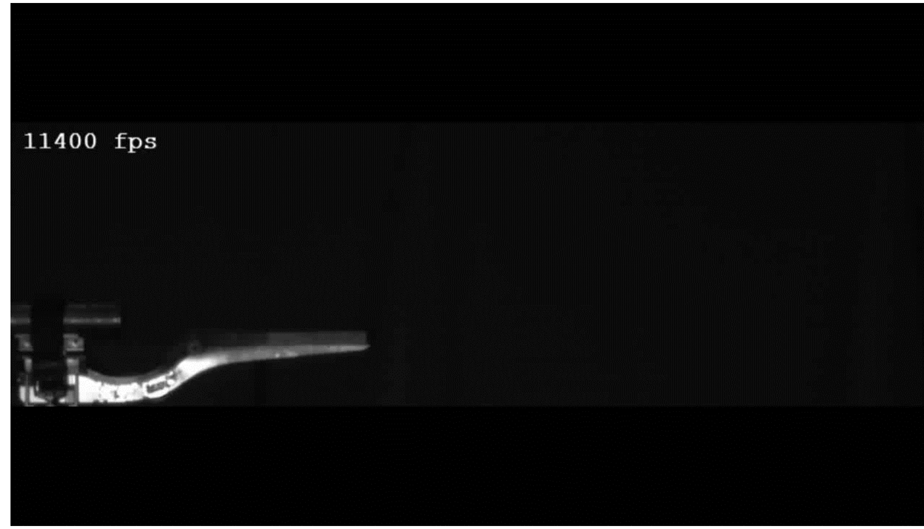
High speed image of projectile mid-flight using mid-wave IR camera (this camera was used to help calibrate timing of other cameras)



Location of mid-wave IR camera in test setup

Projectile Heating Study
High-speed Videos

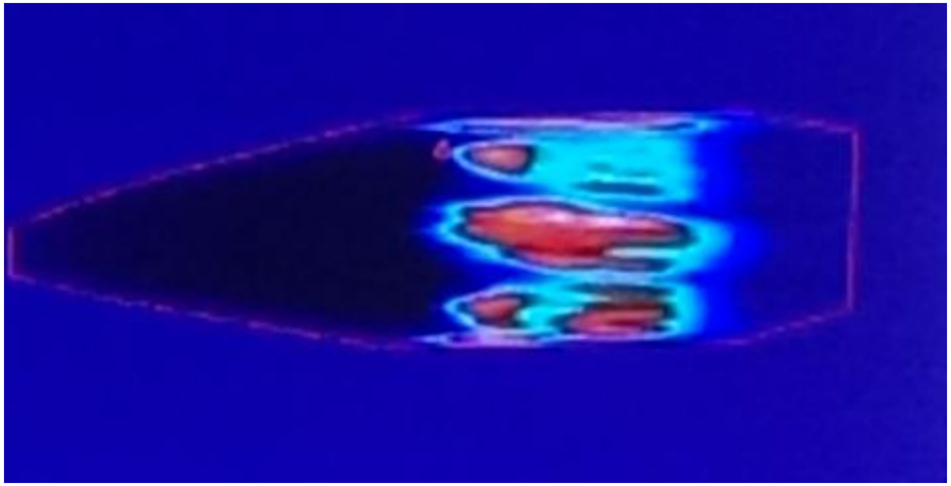
Back view (from picture)



Side view

Front view

Projectile Heating Study
Results

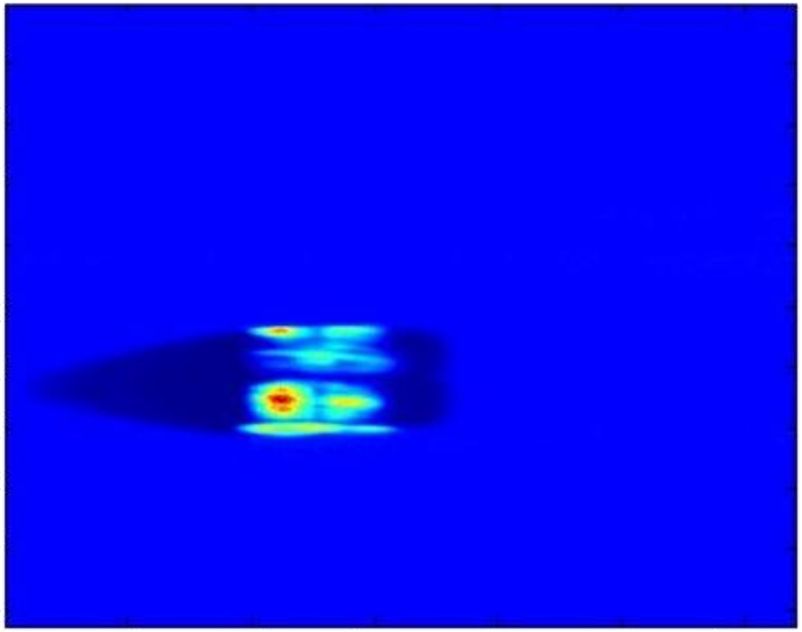


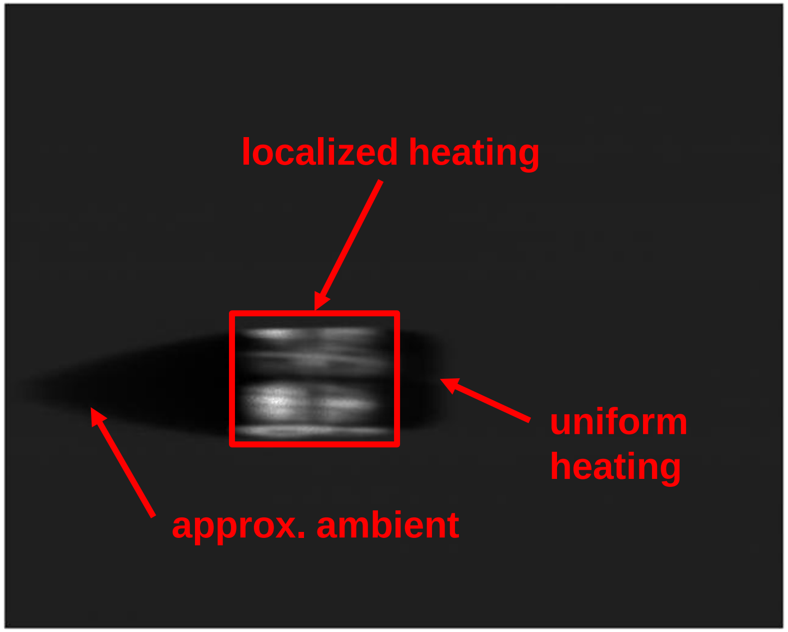
Mid-wave side profile capture (left) and long-wave aft capture (right)

Barrel Length (in.)	Legacy 7.62mm Photos	Current 7.62mm Photos
8	10	20
10	10	20
13	10	20
16	10	20
19	10	20
22	10	20
24	10	20

There were 30 images captured for each barrel. In total, 210 data points were collected.

Projectile Heating Analysis
Captured Data

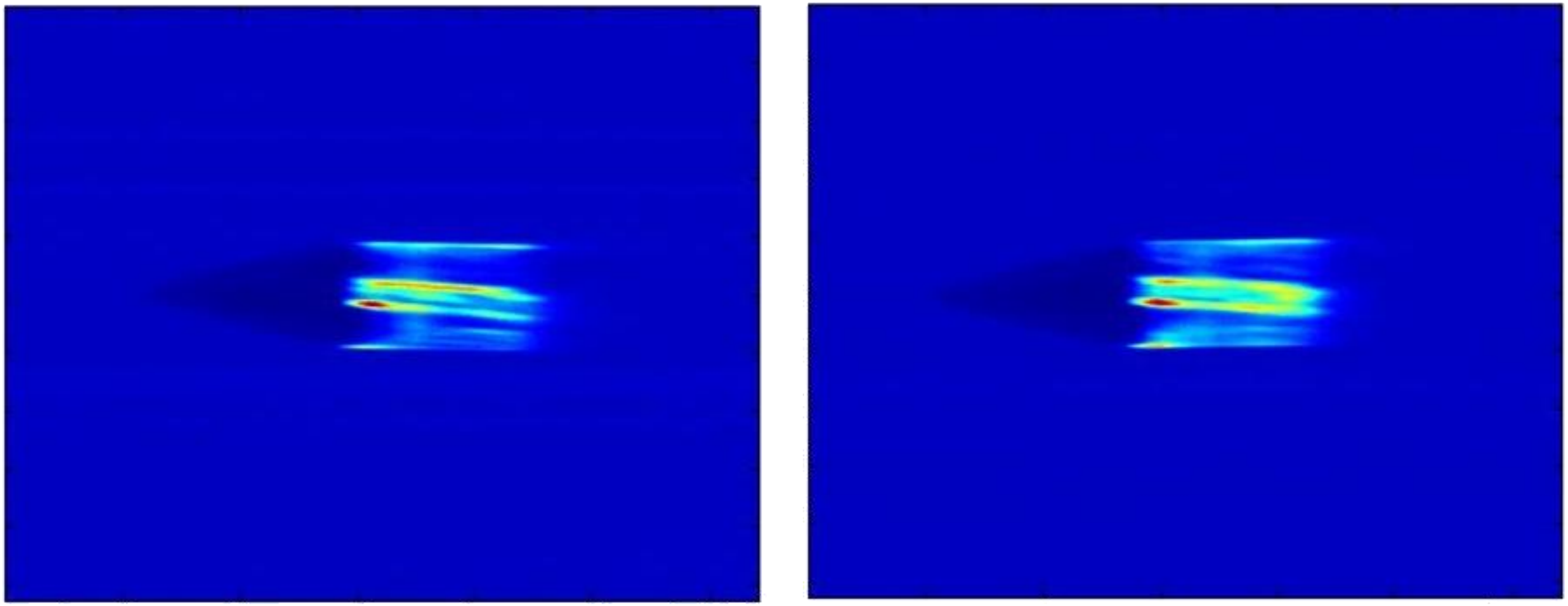




Temperature contour and image of 7.62mm projectile fired from a 24" barrel

- Contours of the surface of the projectile demonstrate two regions of heating: a highly-localized higher temperature region where the bullet was engraved and uniform heating on the back end of the projectile due to propellant gases
- The nose of the projectile remained at approximately ambient temperature

Projectile Heating Analysis
Data Repeatability and Analysis

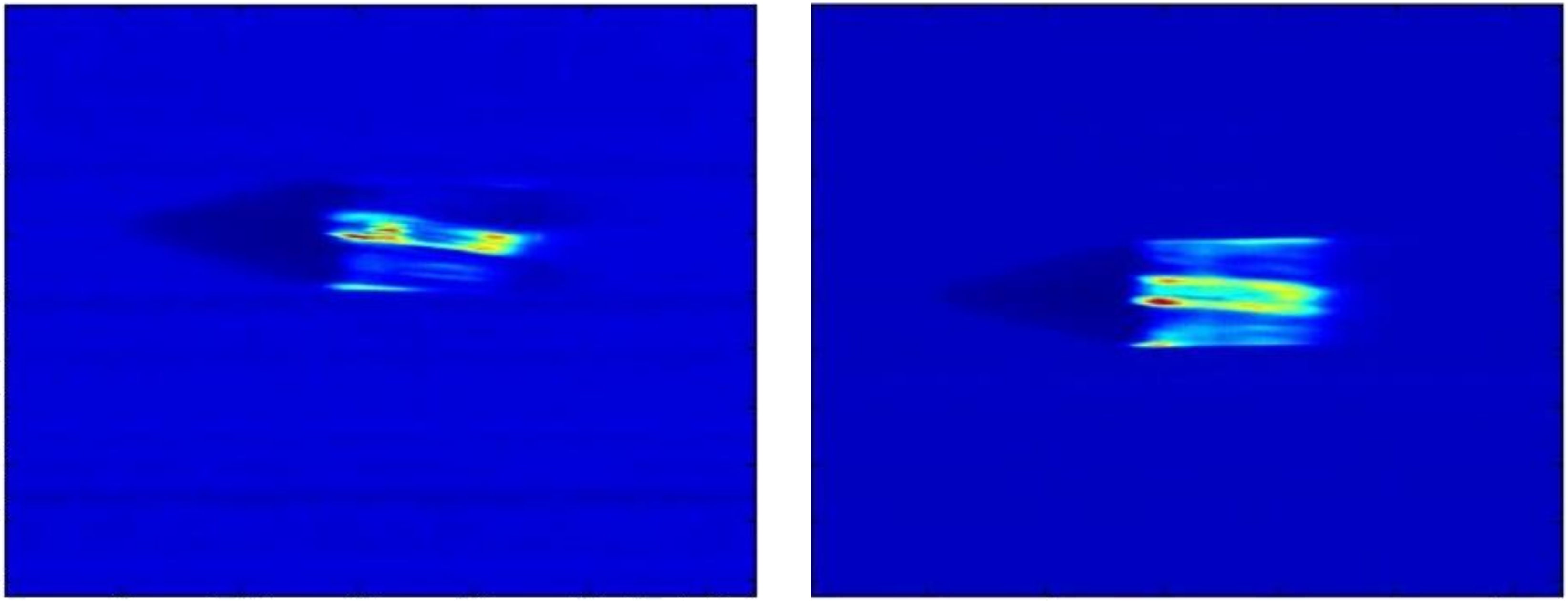


Two independent captures of the 7.62mm projectile immediately after firing, 24" barrel

- Thermal images captured were highly repeatable, with only slight variations in the absolute location of the projectile within the frame

The consistency of the data will allow for the construction of a statistically averaged distribution of values across the surface of the projectile.

Projectile Heating Analysis
Temperature Distribution

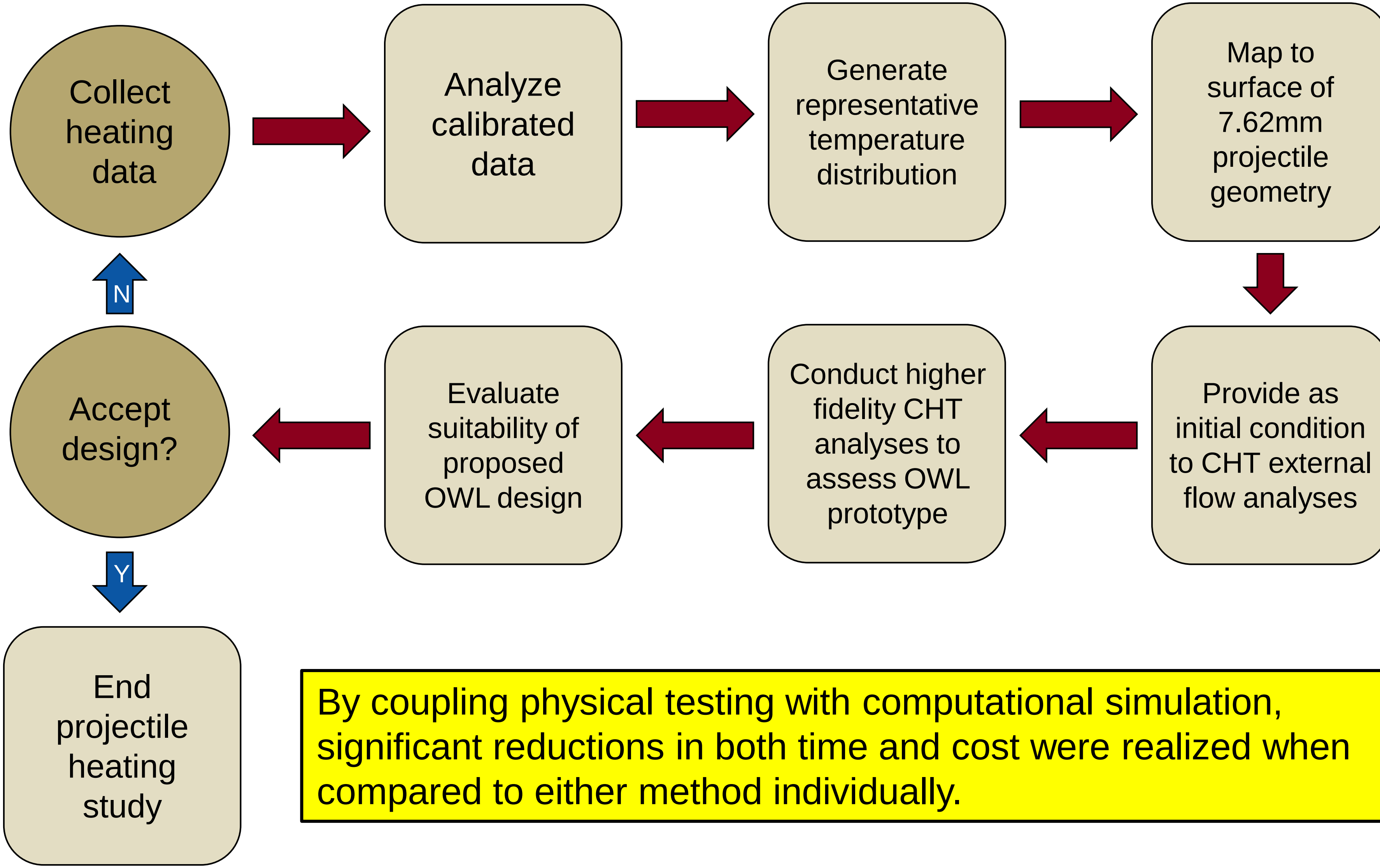


Temperature contours of 7.62mm projectile fired from a 16” barrel (left) and 24” barrel (right)

- There were noticeable differences in the magnitude and spatial distribution of heating caused by the different barrel lengths.

Once statistical temperature distributions have been generated for each tested barrel length, a “heating curve” will be generated to predict the thermal conditions for projectiles fired from weapons systems with barrel lengths between 8” and 24”.

Projectile Heating Analysis
Process Roadmap



By coupling physical testing with computational simulation, significant reductions in both time and cost were realized when compared to either method individually.

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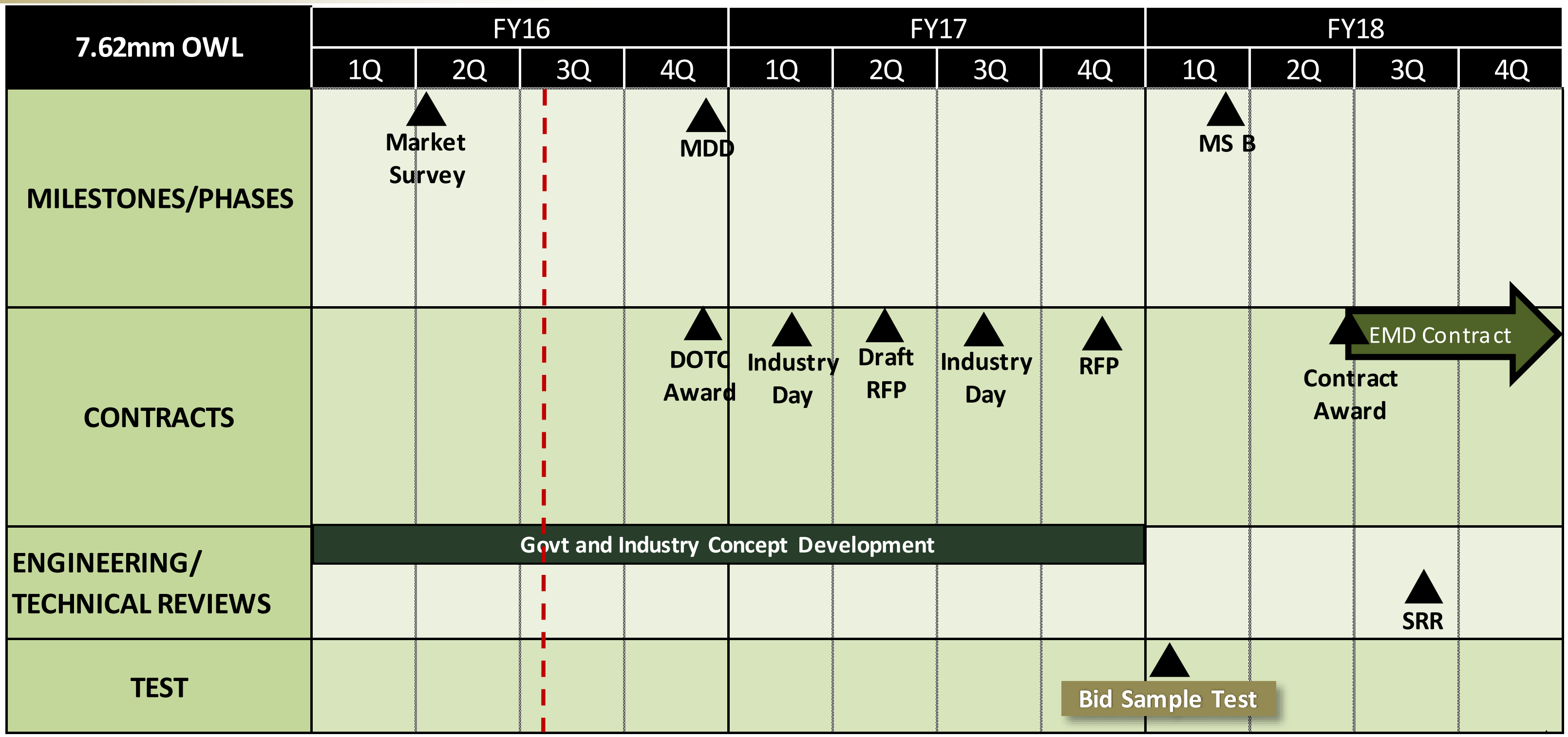
Projectile Heating Analysis
Future Applications

- Multiple applications beyond the scope of this project
  - In-bore heating of a temperature-sensitive munition is critical to mission requirements.
  - Procedure developed here is easily repeatable, and can be conducted for a variety of weapons systems
  - Some possible future applications include:
    - OWL system for 5.56mm round
    - OWL system for .50 Cal round
    - Other specialty small caliber rounds

OWL effort helped create a capability to expand technology investigations with innovative modeling and simulation techniques that can further enhance current and future Small Caliber Systems development.

OWL Development Schedule



- MS B planned for 1st QTR FY 18
- Two industry days planned over the next 15 months for EMD contract
- EMD anticipated to be 3 year effort to achieve MS C
- Anticipated LRIP options after the EMD contract

Program Conclusion and Path Forward

- USG has developed significant effort to advance OWL, and had multiple concepts that are in the running for MSB technologies
- In order to adequately evaluate technologies, USG has been updating and synthesizing its process to capture and assess events
- Due to the unique nature of OWL and new technology areas, the USG needed better information in situ events/energy
  - Led to developing an innovative and unique analysis tool to assist in technology evaluation prior to prototype builds
  - M&S tool will be able to provide more information about interior ballistic environments during simulated events
- Timeline for EMD is rapidly approaching, OWL program is expected achieve MSB in 1st QTR FY18

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Questions?