Mid-Scale Testing and Simulation of Fuze Terminal Ballistic Environments

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APPLIED RESEARCH ASSOCIATES, INC.

An Employee-Owned Company

Overview

- Test Objectives

- Gun Test Setup

- Target Design

- Range and On-board Instrumentation

- Reverse Ballistics Testing

- High-fidelity Finite Element Modeling Comparisons

- High Speed Photo Data Review

- On-board Data Review

- Test Data Comparisons with Pre-test Predictions
  - SAMPLL Test and Target Design Calculations

- Conclusions

**Expanding the Realm of Possibility**

Test Objectives

- Collect high-quality deceleration time-history data during high-speed multi-layered, multi-material penetration events:
  - With multiple combinations of
    - concrete layers of 0.2, 0.8, and 1.5 body lengths,
    - thick soil layers
    - multi-body length voids
  - With lateral loading and angle of attack conditions (simulated with angle of impact)
  - With angle of impact reversals
  - Data suitable for calibrating high-fidelity computational models
  - Data suitable for validating SAMPLL (Simplified Analytical Model of Penetration with Lateral Loading) code, used for pretest test and target design

Gun Test Setup

Range Instrumentation

- Image Motion cameras used to determine impact attitude and velocity

- High-speed film and video cameras at various locations

- Crush gauges and Velocity screens

Concrete Stopper Blocks
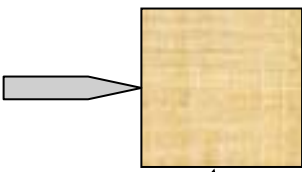
Concrete

Soil

Concrete

Concrete

Flight Line
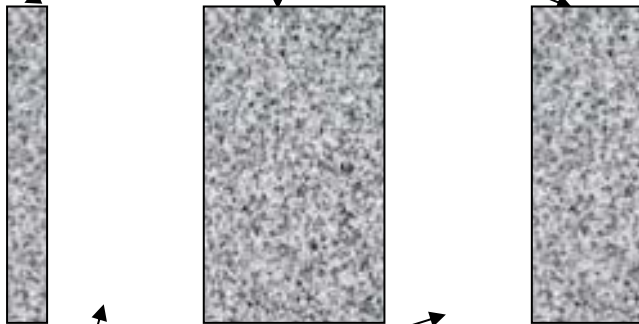
Image Motion Camera
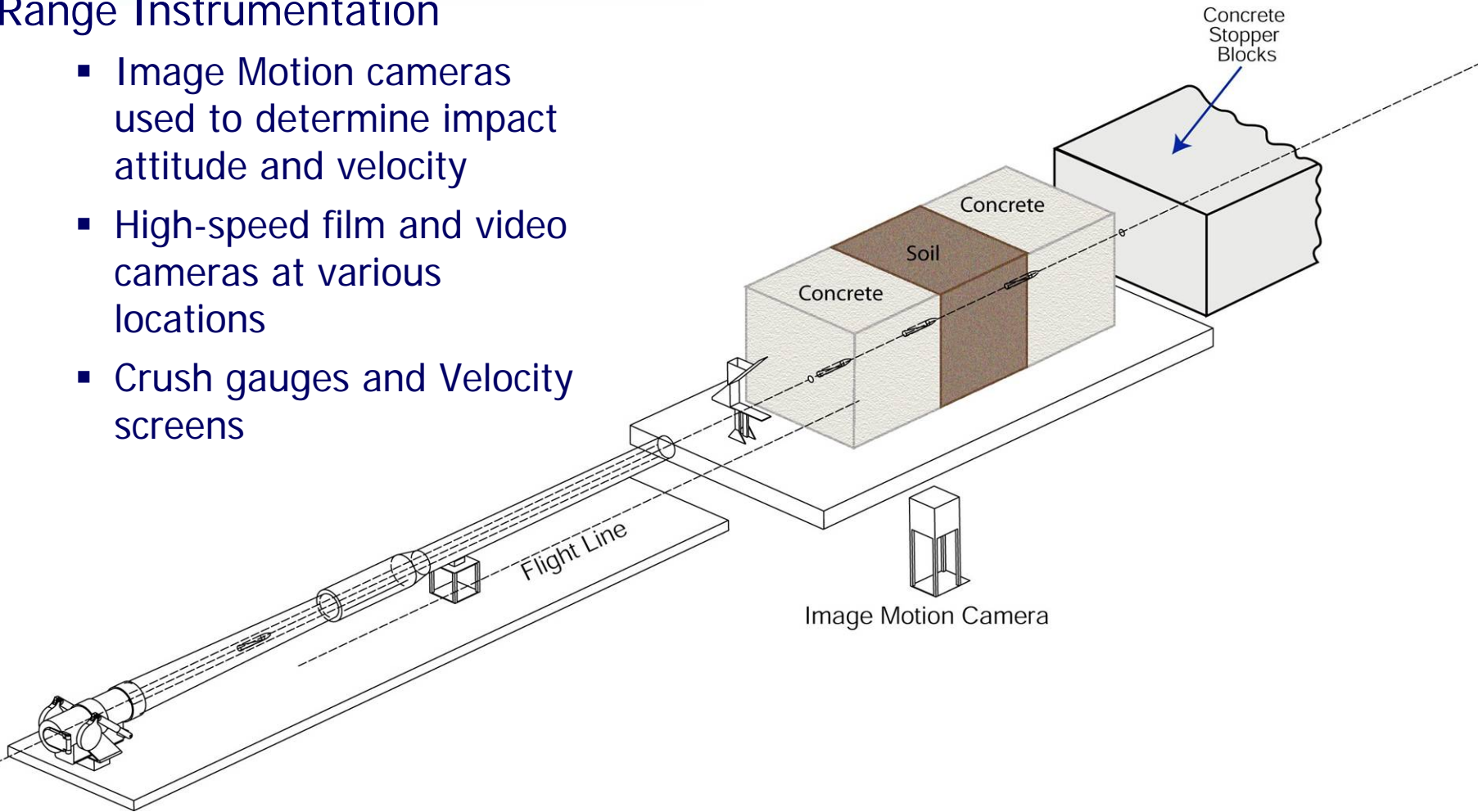
Target Design - MD 1-4 (2800 ft/sec)

Concrete Target Blocks 0.2, 0.8, 1.5 BL
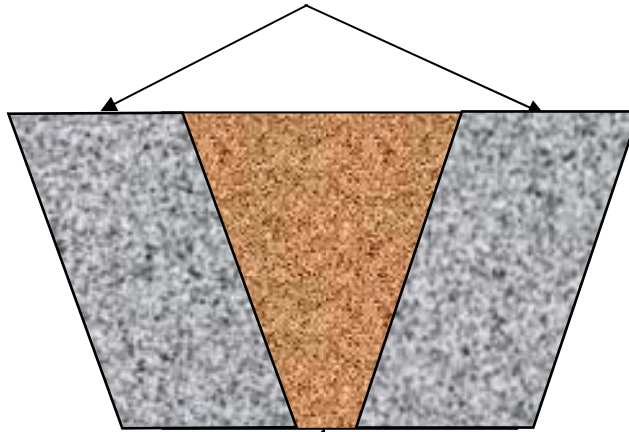
Concrete Stopper Blocks
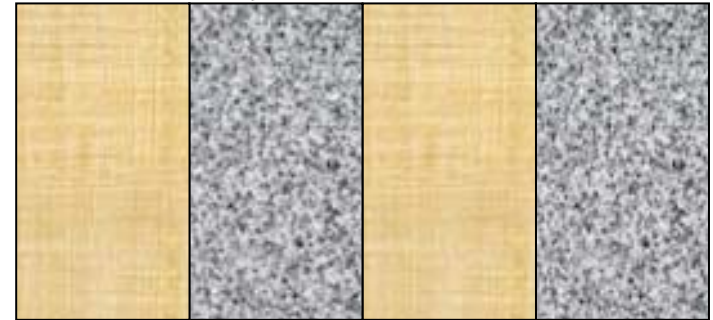
Plywood Sabot Stripper

Thick Soil

Plywood Stopper Blocks
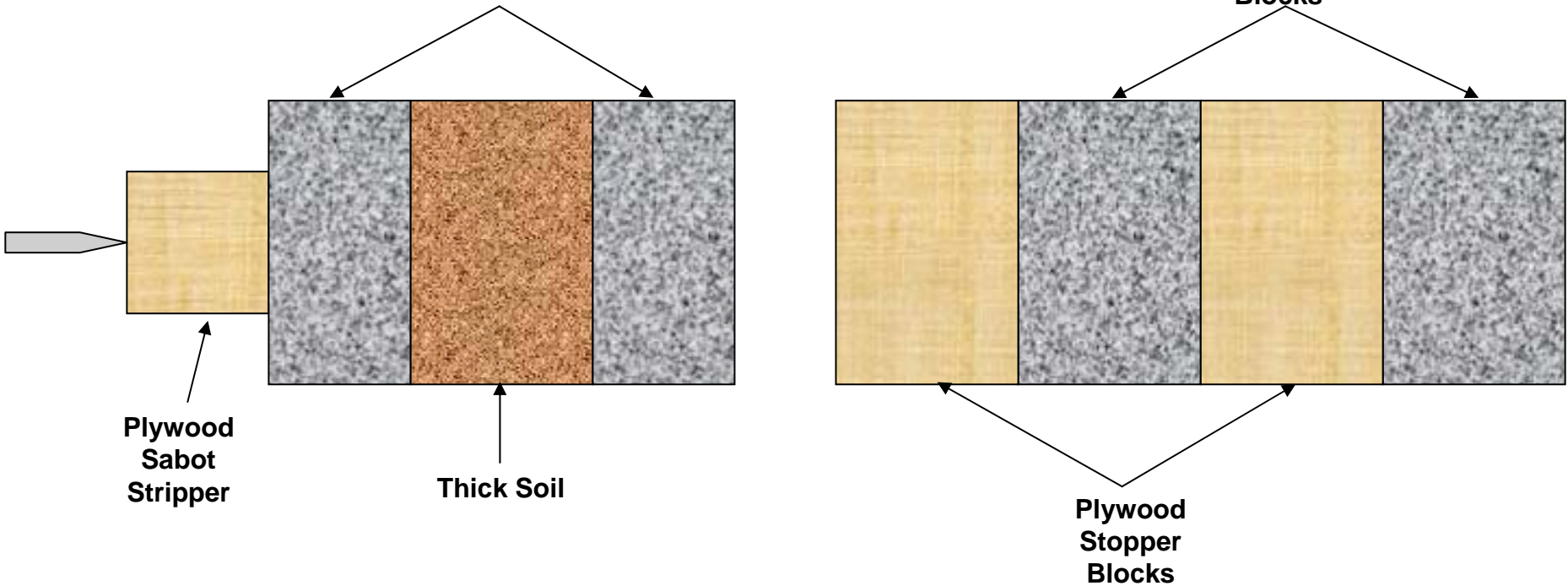
NOT TO SCALE

Target Design – MD A & B (2350 ft/sec)

Concrete Target Blocks 0.2, 0.8, 1.5 BL

Concrete Stopper Blocks

Plywood Sabot Stripper

Multi-BL Voids (Air)
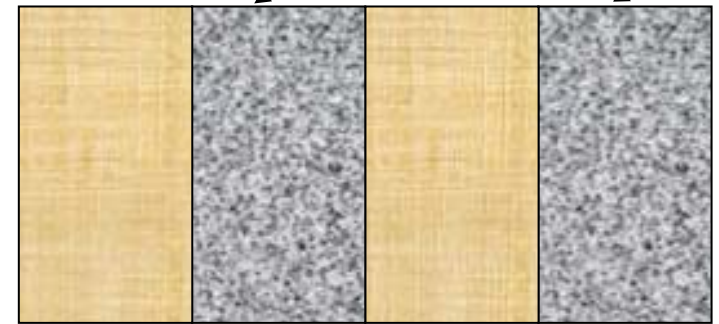
Plywood Stopper Blocks

NOT TO SCALE

Target Design - MD C (2350 ft/sec)

Angle of Impact Reversal Lateral Loading Concrete Target Blocks

Concrete Stopper Blocks

Plywood Sabot Stripper

Thick Soil

Plywood Stopper Blocks

NOT TO SCALE

Expanding the Realm of Possibility

Target Design - MD D (2350 ft/sec)

Angle of Impact Reversal Lateral Loading Concrete Target Blocks

Concrete Stopper Blocks

Plywood Sabot Stripper

Multi-BL Voids (Air)

Plywood Stopper Blocks
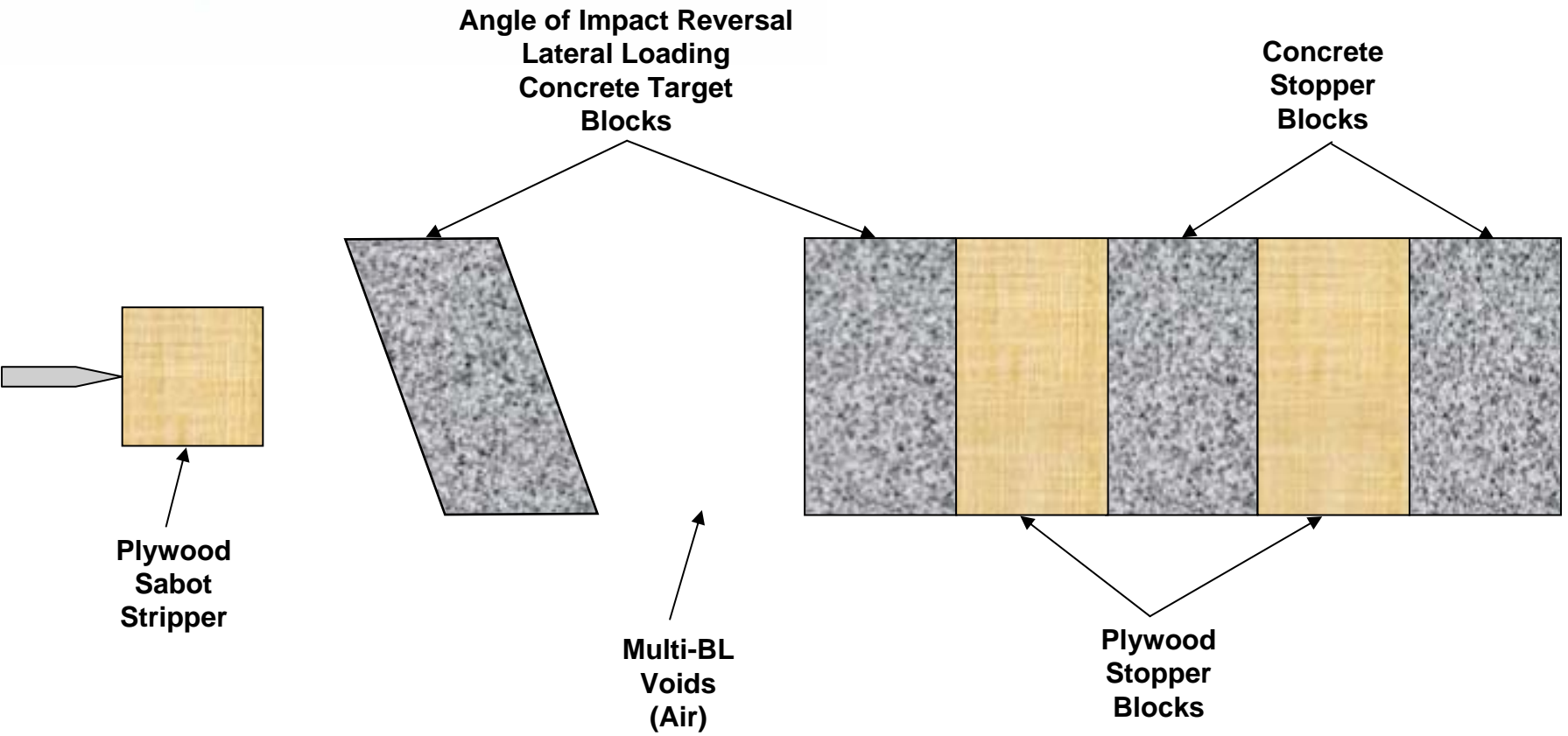
NOT TO SCALE

Test Range: Energetic Materials Research and Testing Center (EMRTC), Socorro, NM

Additional Recoil Capacity

APR 20 2004

Expanding the Realm of Possibility

Barrel Clamps (one of three) Limit Whip

Expanding the Realm of Possibility

Muzzle Exit Crush Gauges

Expanding the Realm of Possibility

On-board Data Package

Lock Rings

Accelerometer Blocks

Battery Packs

Lock Rings

Solid Rod

IES Model 64 Recorders

Nose Plug
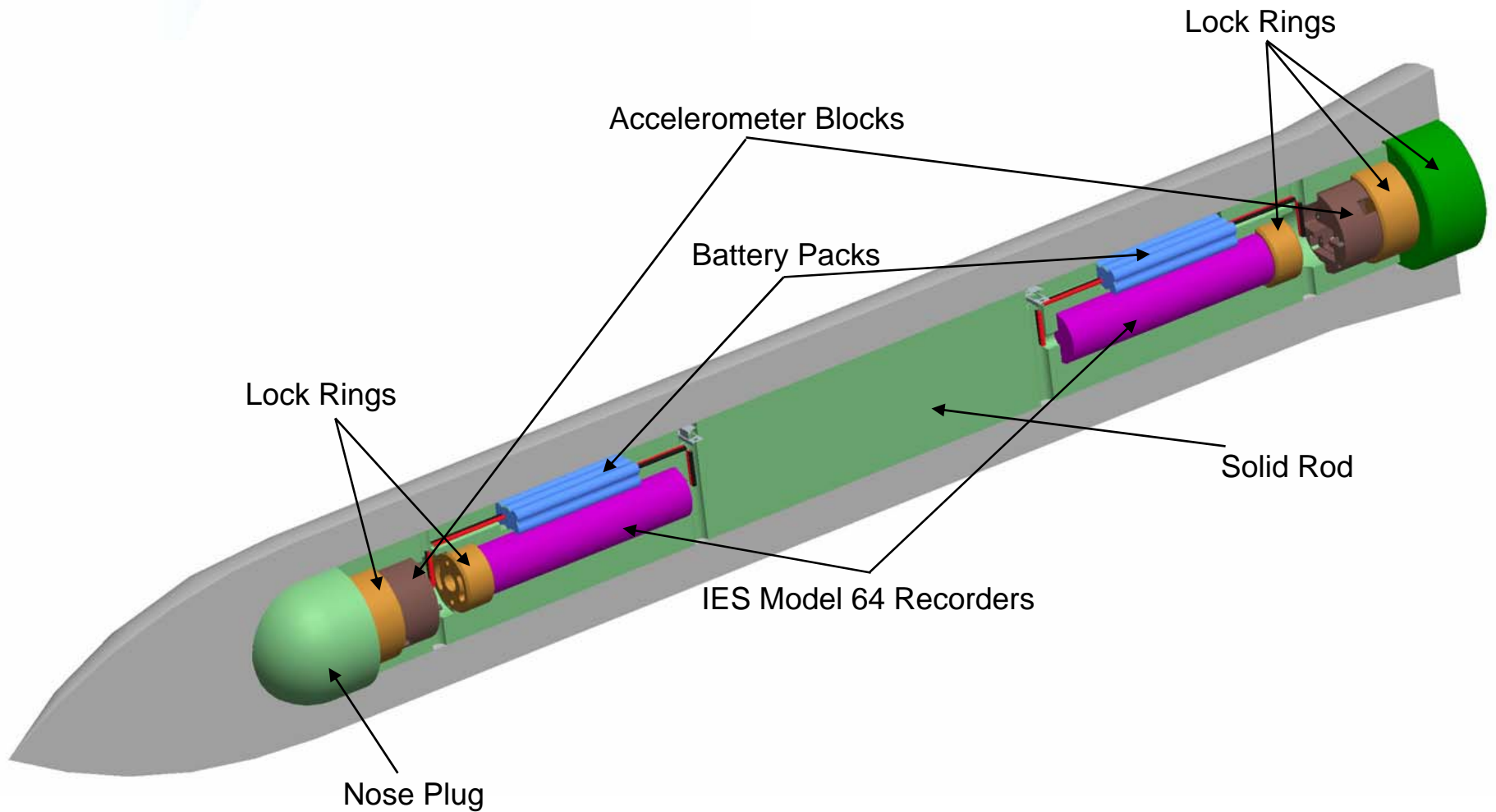
Accelerometer block with mounted X-axis Accelerometer
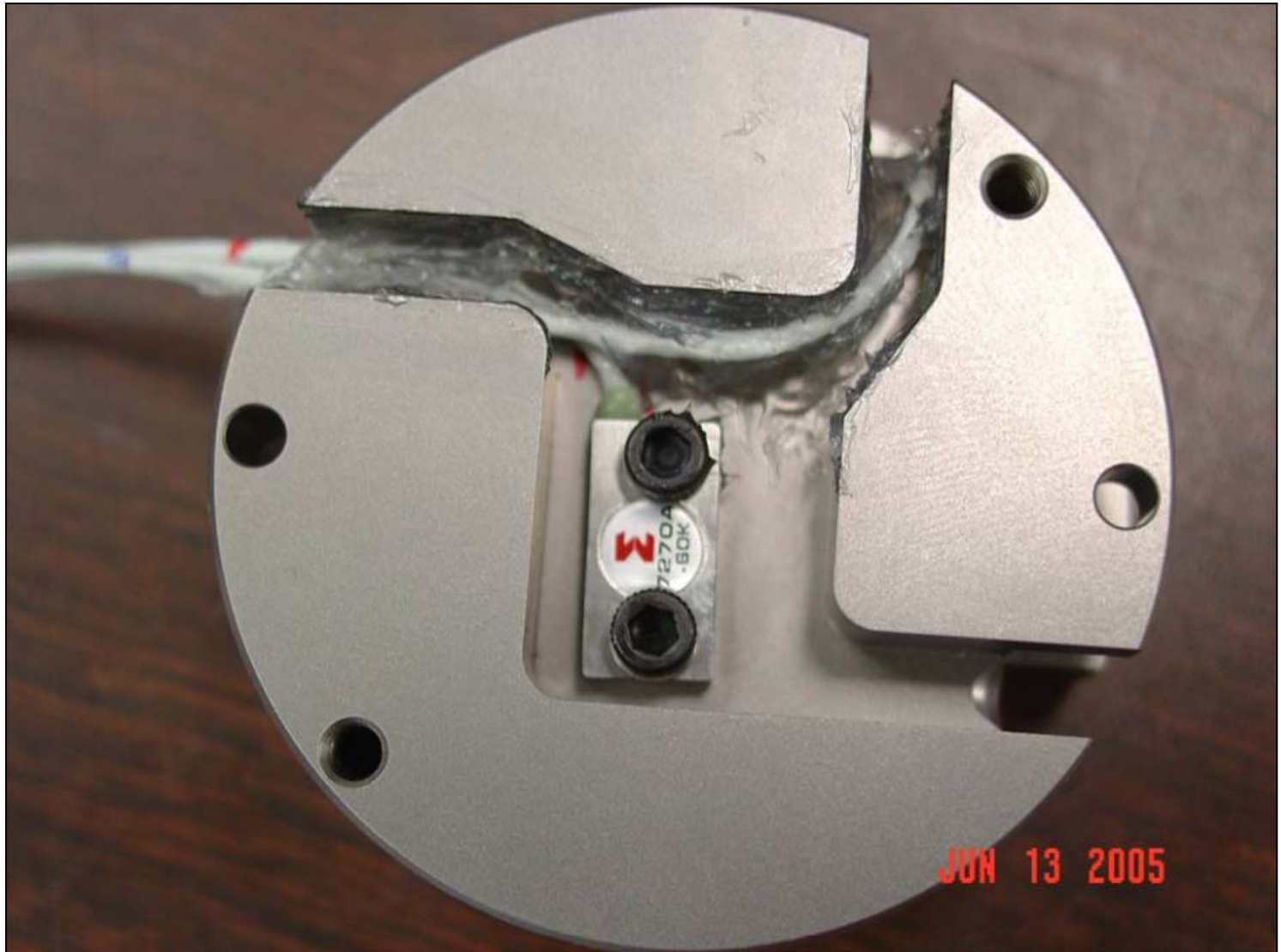
Accelerometer block with mounted Y-axis (or Z-axis) Accelerometer

Accelerometer block with three X-axis Accelerometers in "L" Configuration

Expanding the Realm of Possibility

Assembled Penetrator and Sabot

Expanding the Realm of Possibility

Sabot/Pusher Plate/Obturator Design

Expanding the Realm of Possibility

LS-DYNA FEM Model
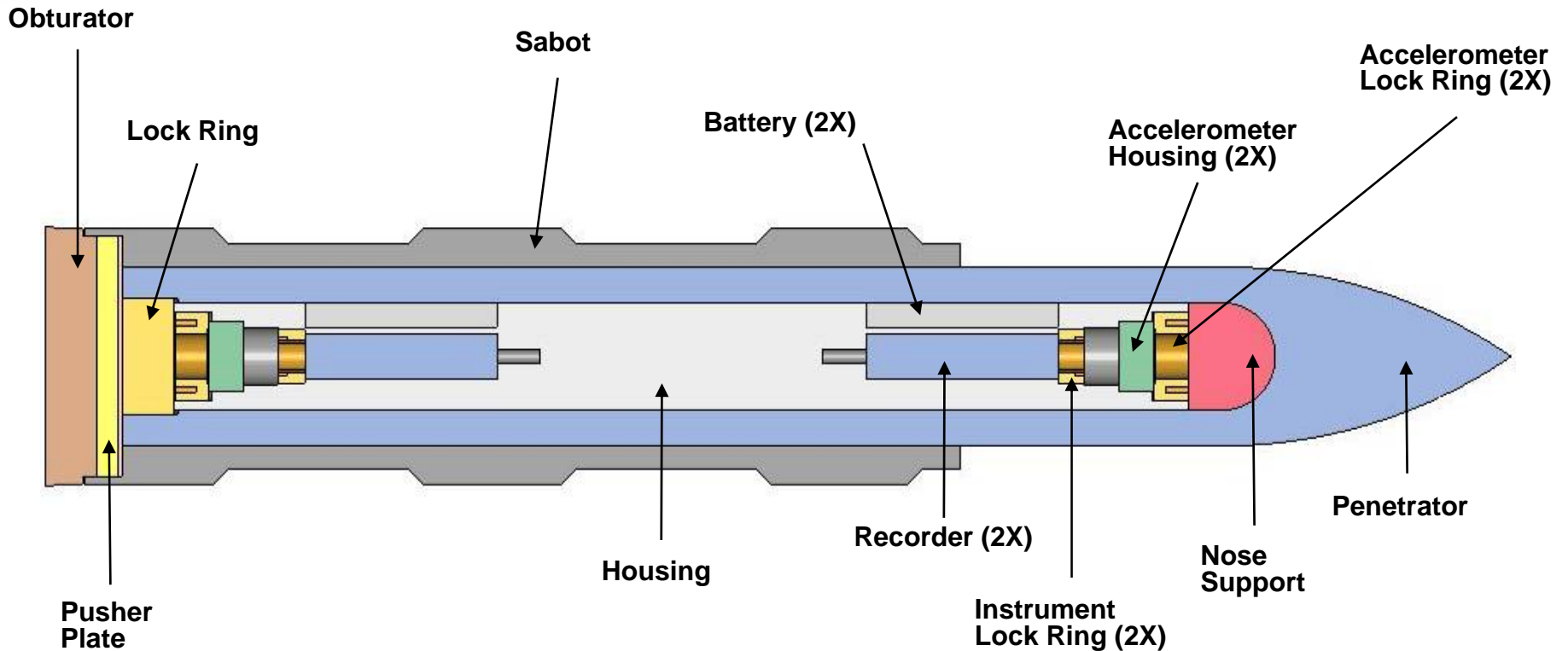
Normal Impact Early Timeline

t = 0.00 ms
Penetrator nose contacts plywood.

t = 0.30 ms
Sabot pulls forward as penetrator slows down.

t = 0.48 ms
Sabot impacts plywood.

ARA

20
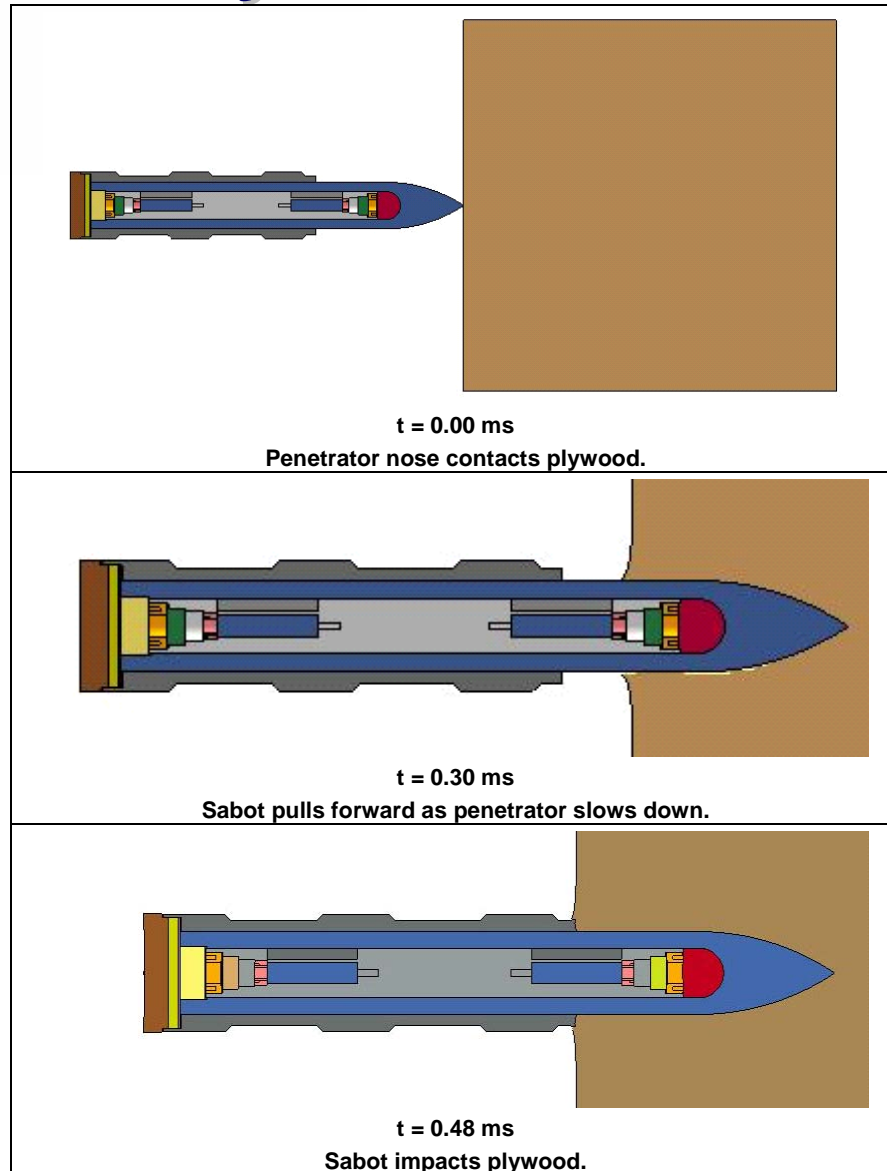
Close Up of Sabot – Pusher Plate/Obturator Gap at 0.90 ms
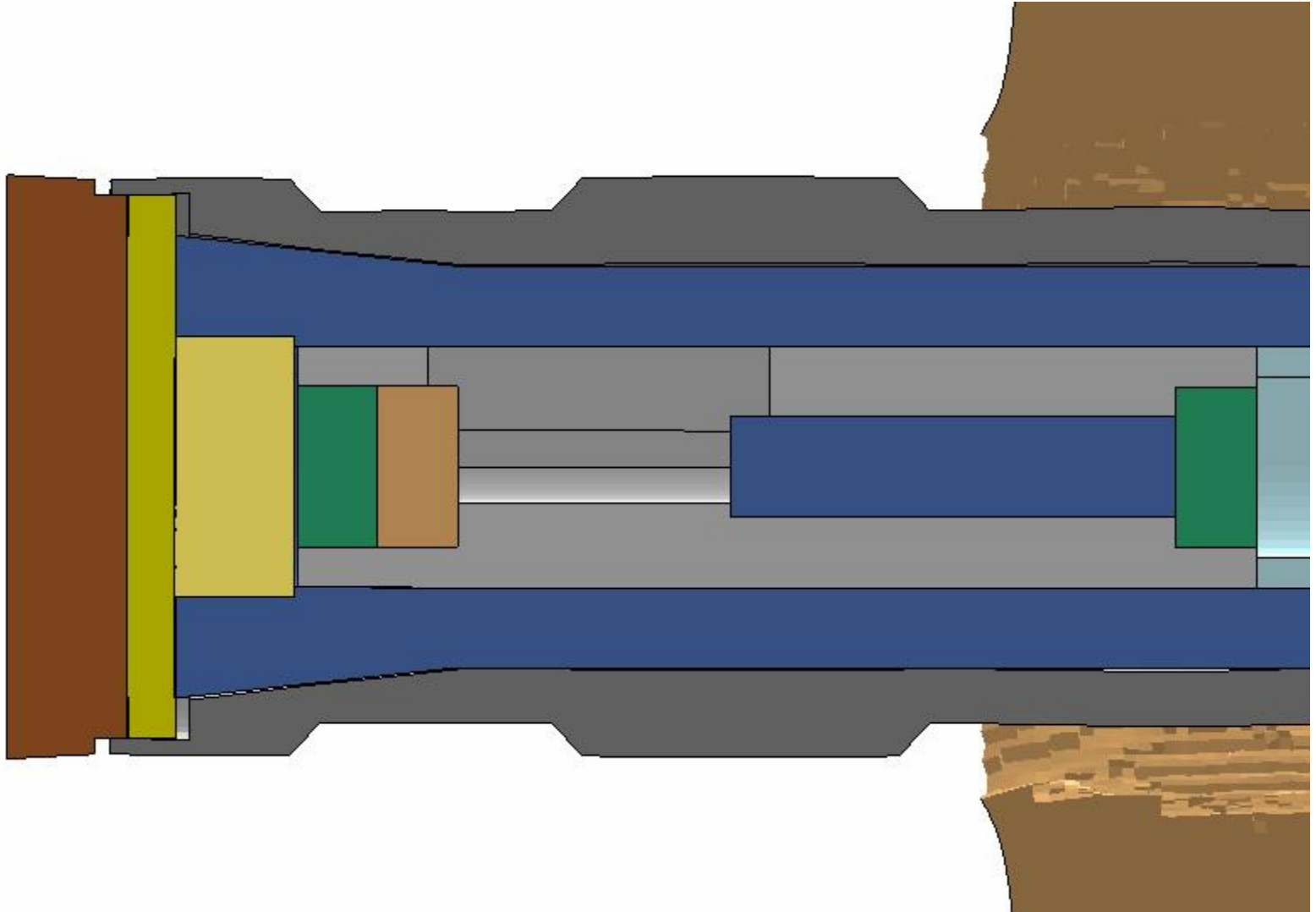
Sabot – Pusher Plate/Obturator Gap Closed at 1.06 ms
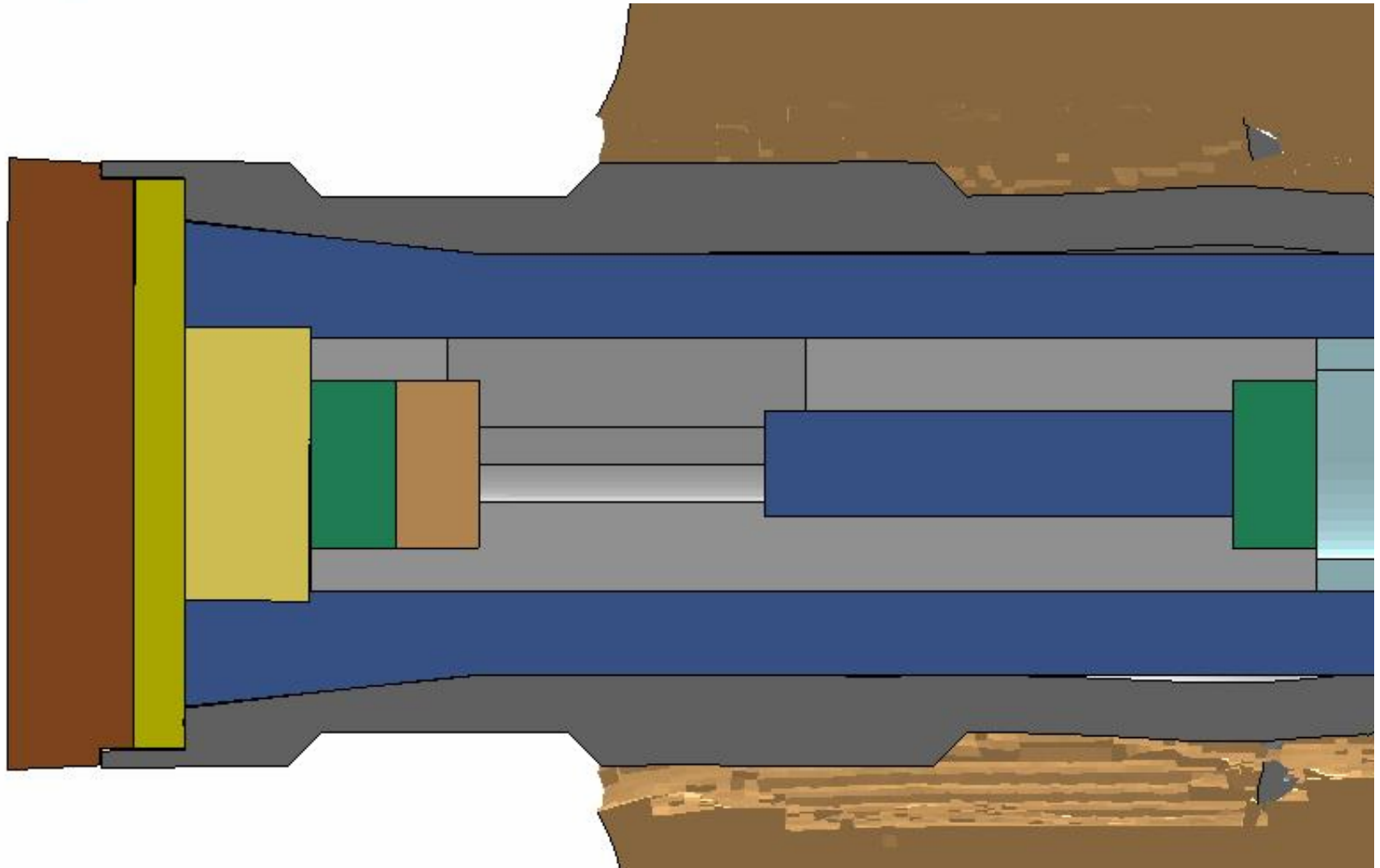
Normal impact with velocity contours in the impact direction

t = 0.00 ms

t = 0.30 ms

t = 0.48 ms

t = 0.80 ms

t = 1.06 ms

t = 1.36 ms

2 degree AOA

t = 0.00 ms

t = 0.30 ms

t = 0.56 ms

t = 0.80 ms

t = 1.06 ms

t = 1.36 ms

Expanding the Realm of Possibility
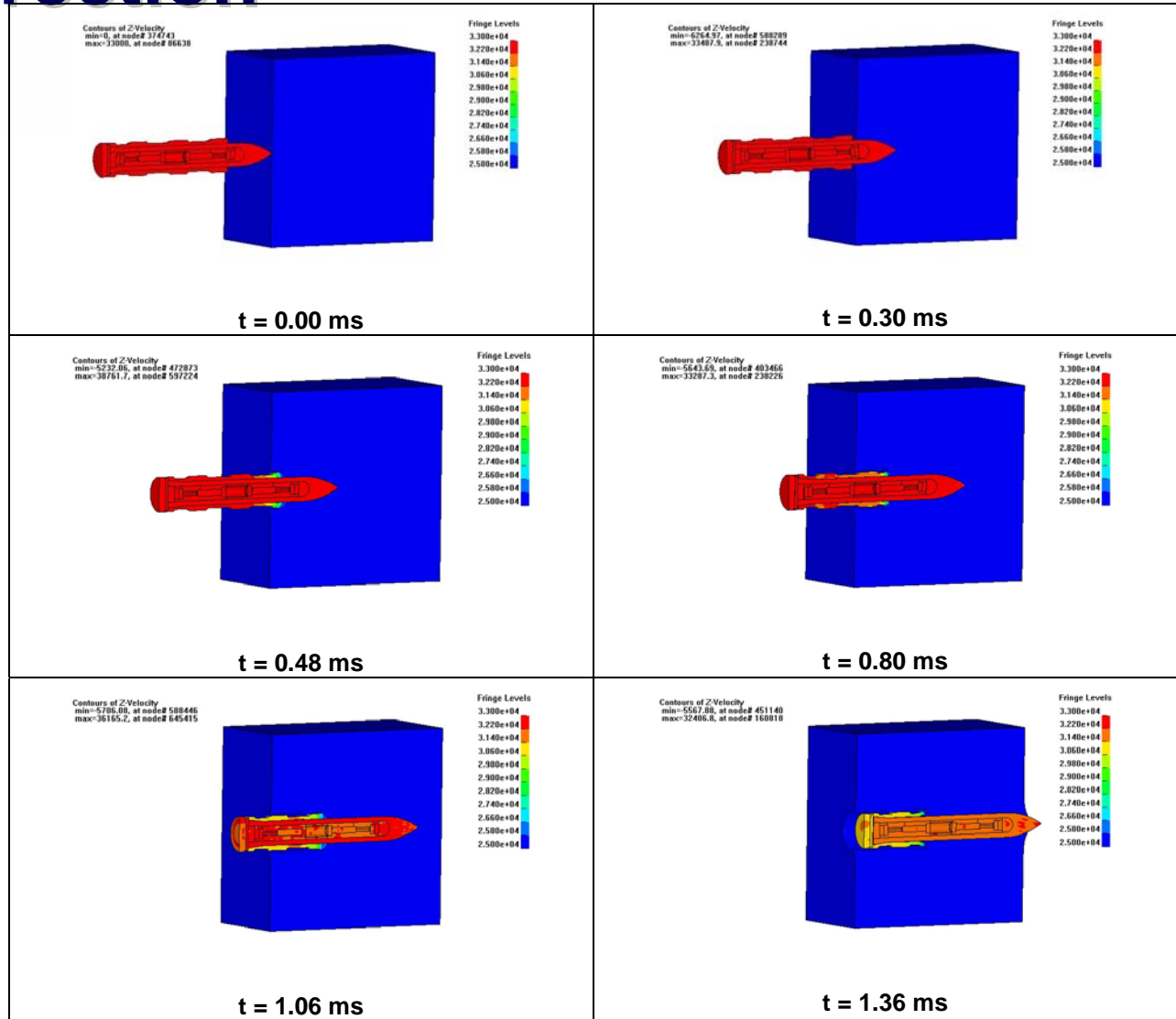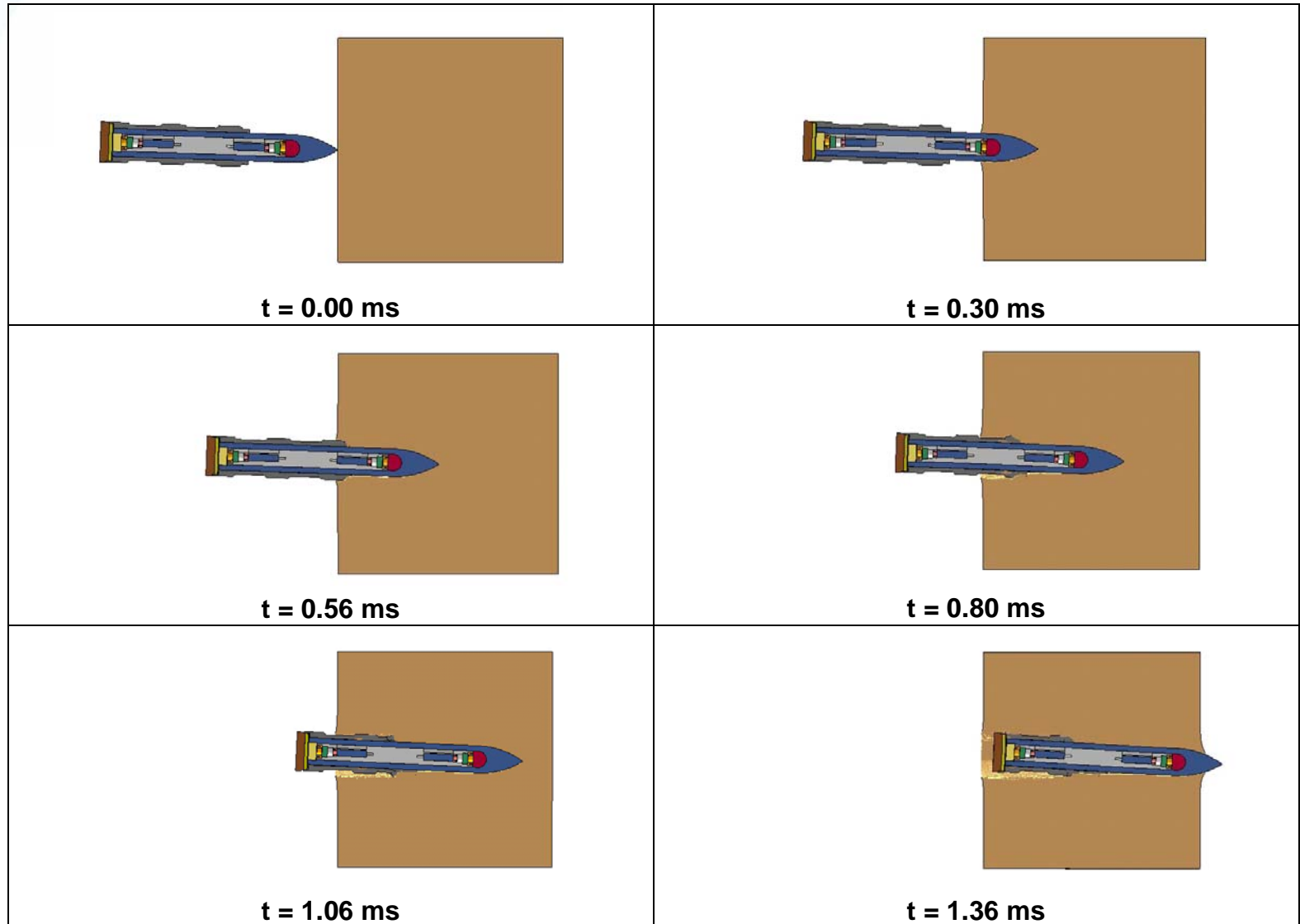
Filtered Simulation Data Compared to Test (10 kHz low-pass)
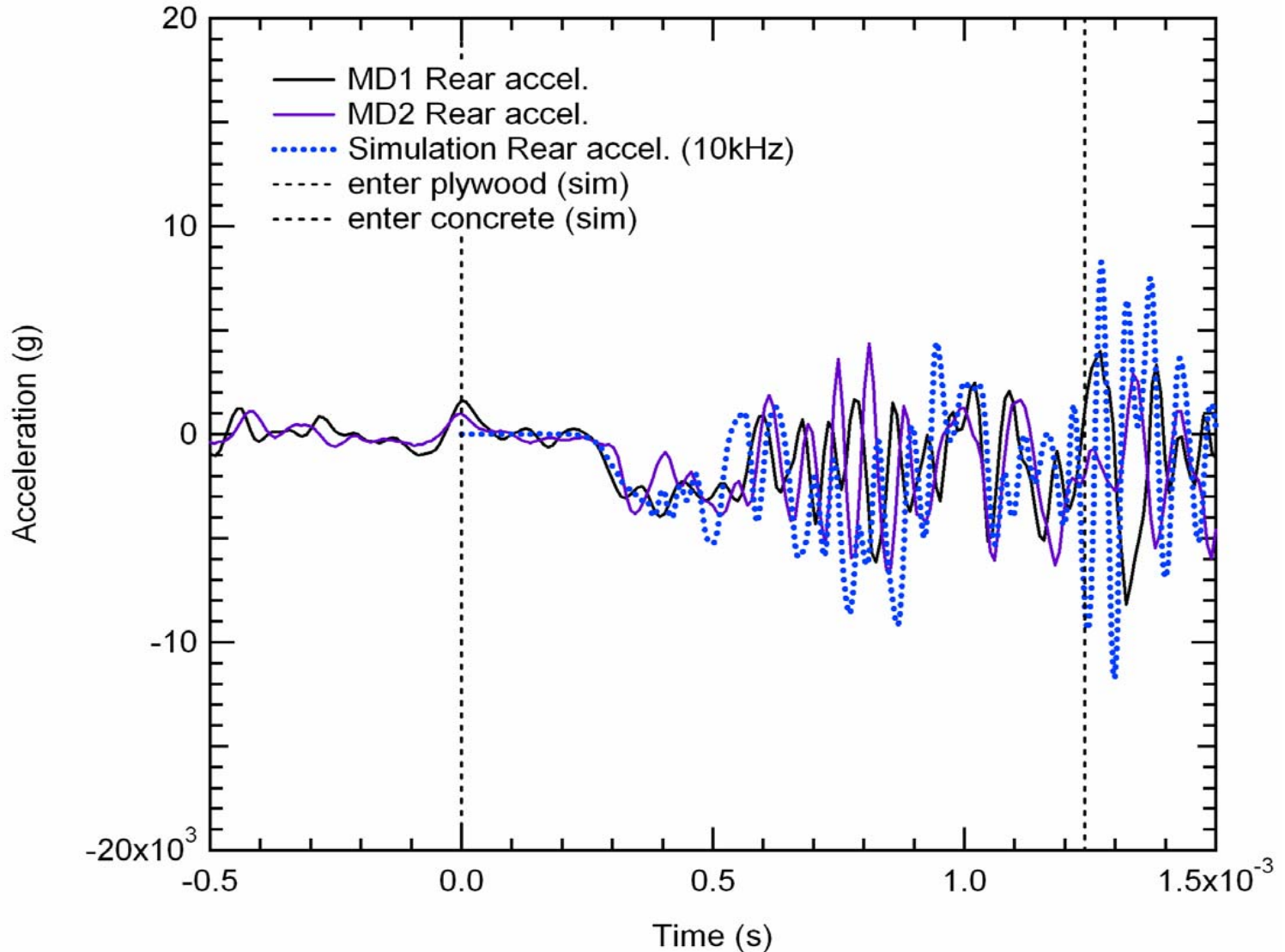
Reverse Ballistics Test Setup (615 lbs, 2000 ft/sec)
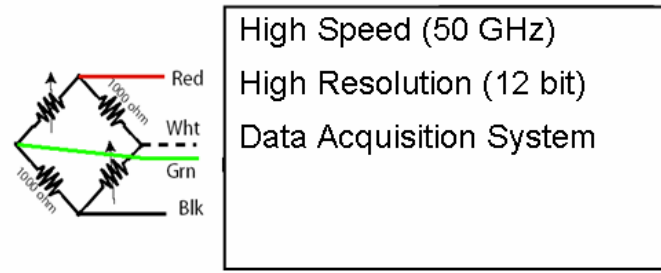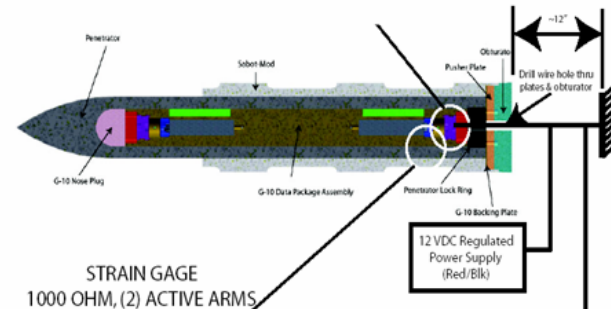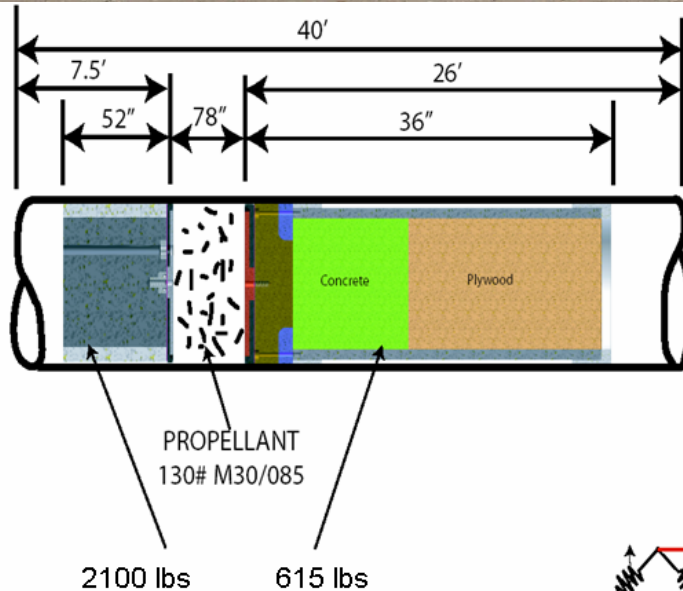
Gun Test Target Setup

Orthogonal Mirror showing Yaw Measurement

MD B Image from Phantom 1
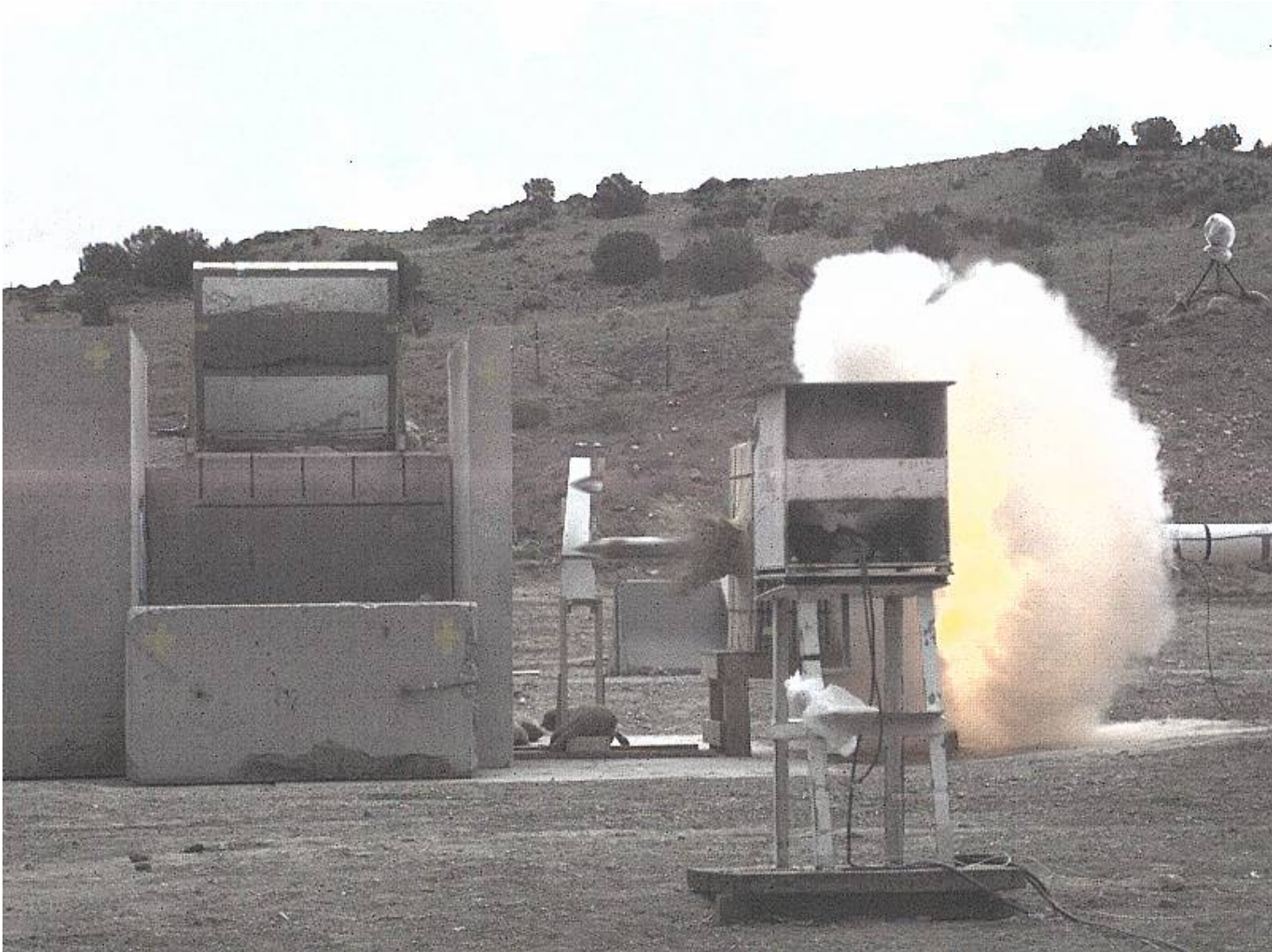
MD B Image from Phantom 1
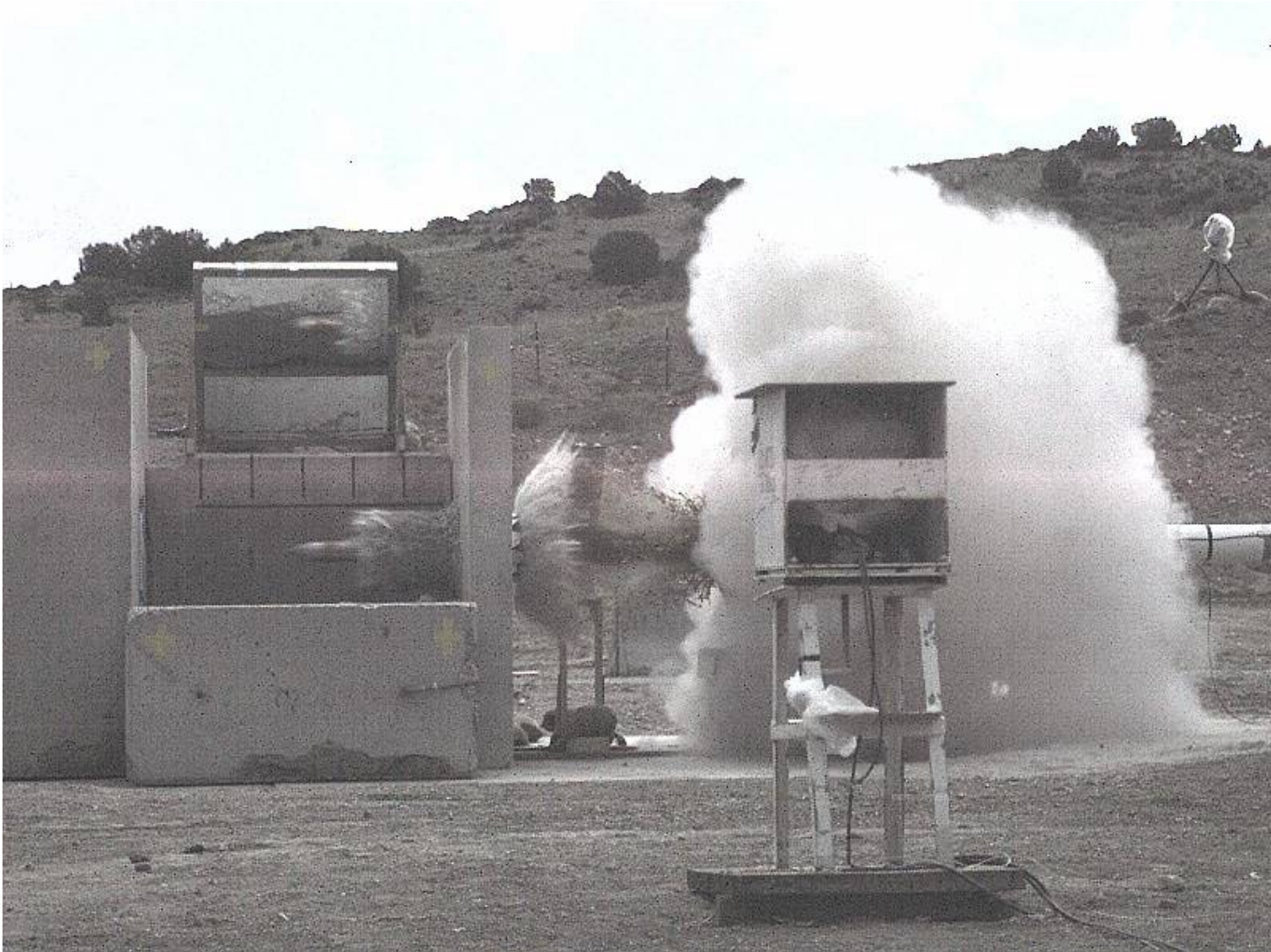
MD B Image from Phantom 2

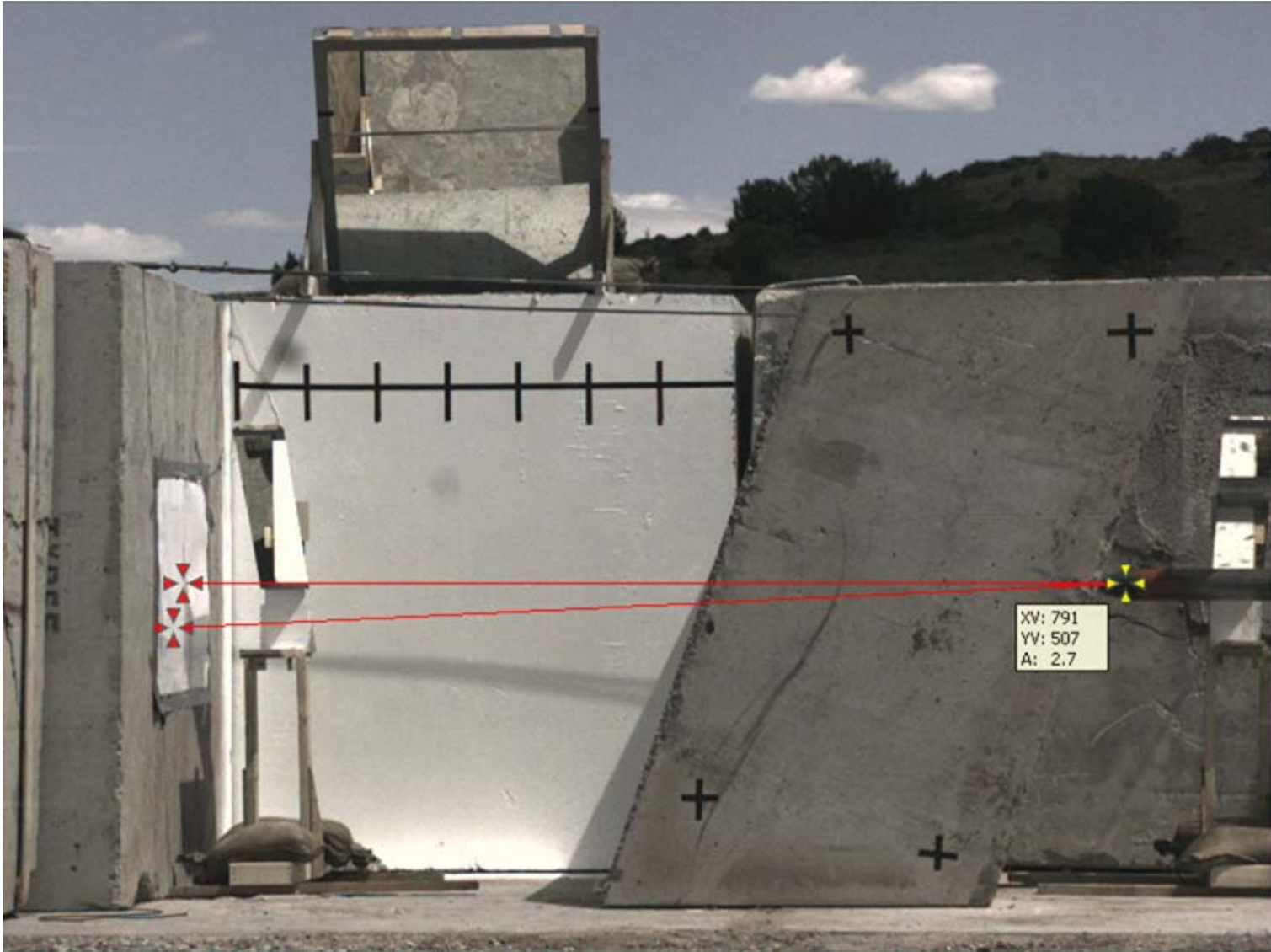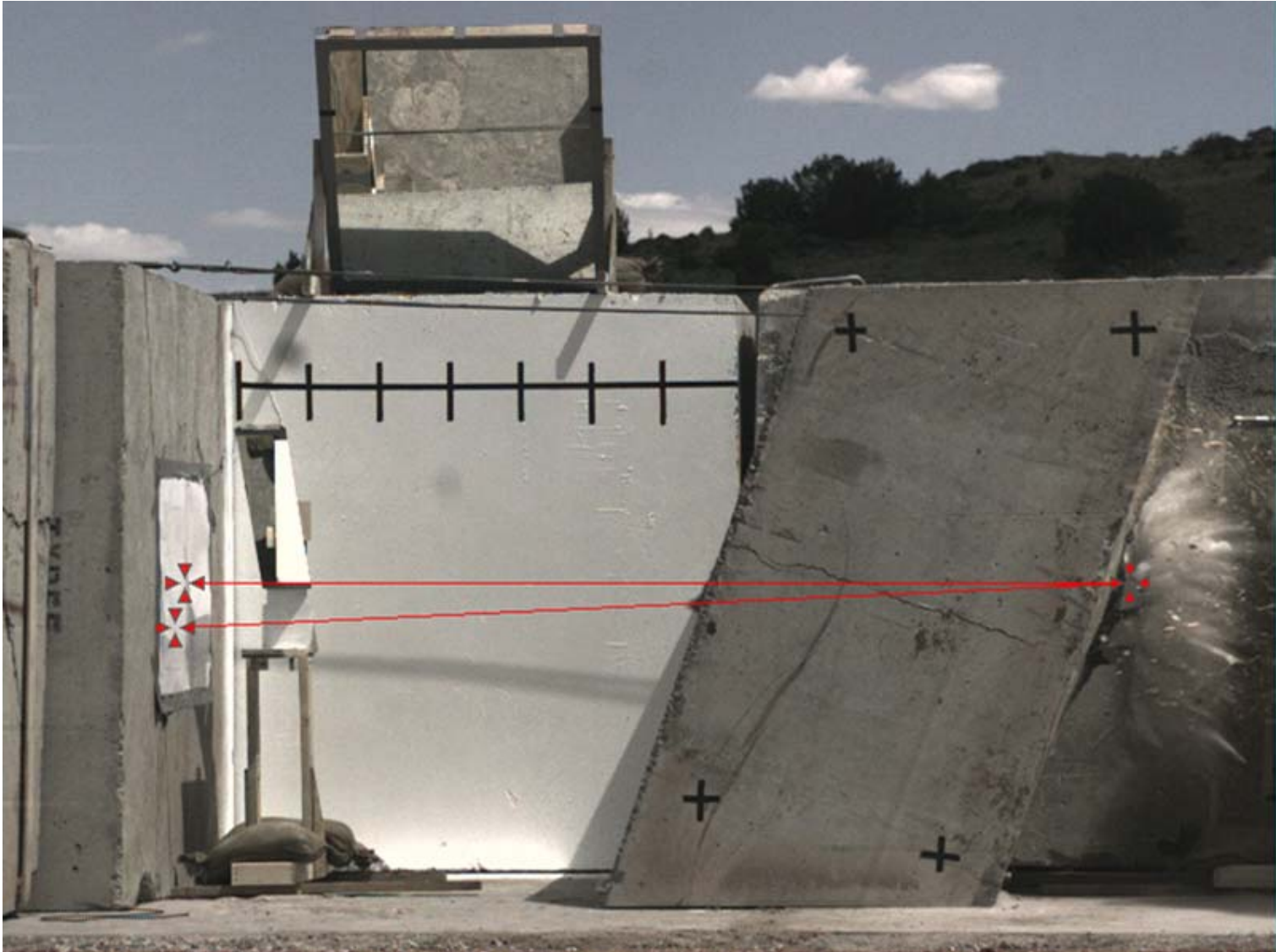# MD B Image from Phantom 2

MD B Image from Phantom 3

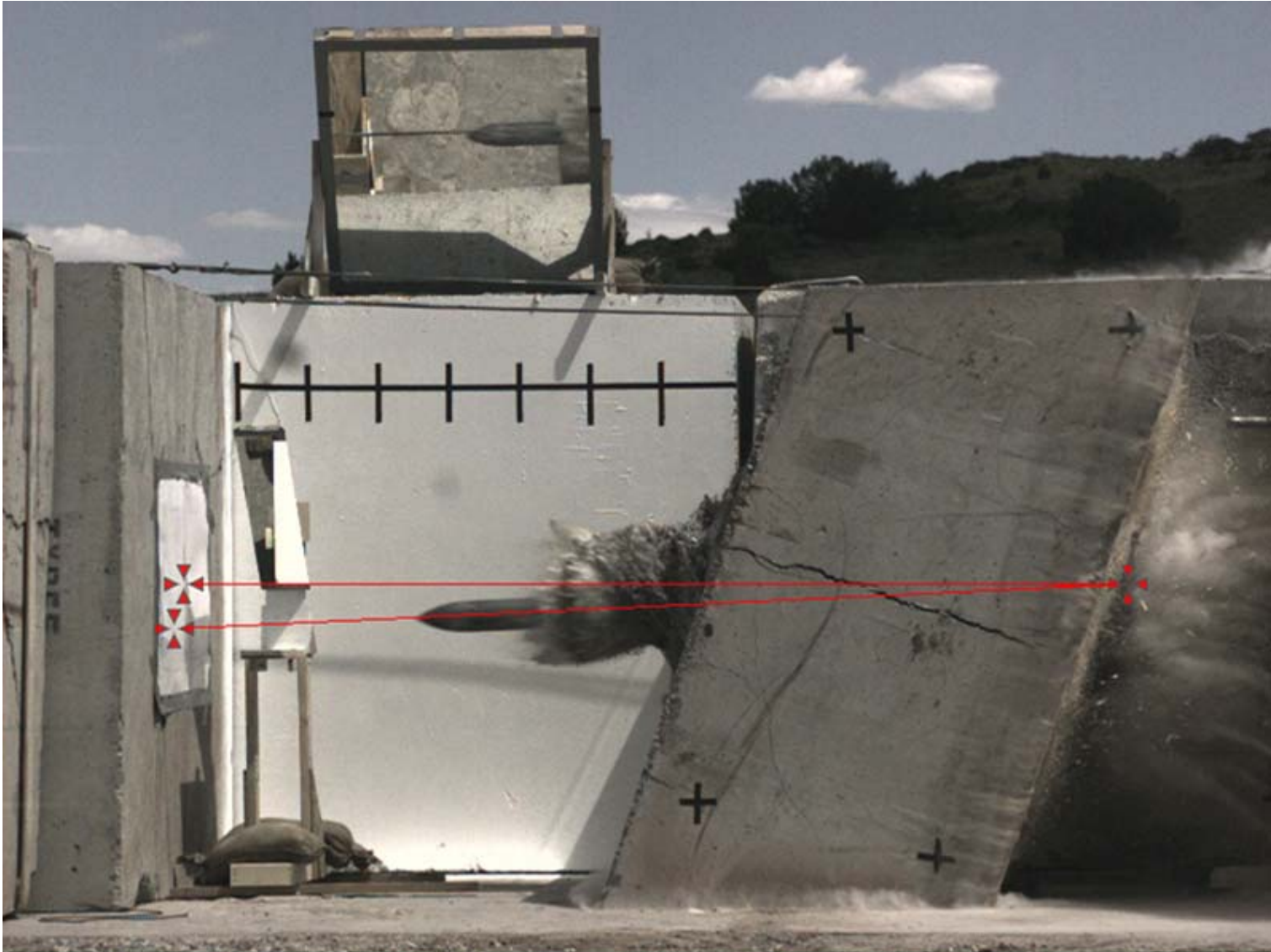# MD D Setup

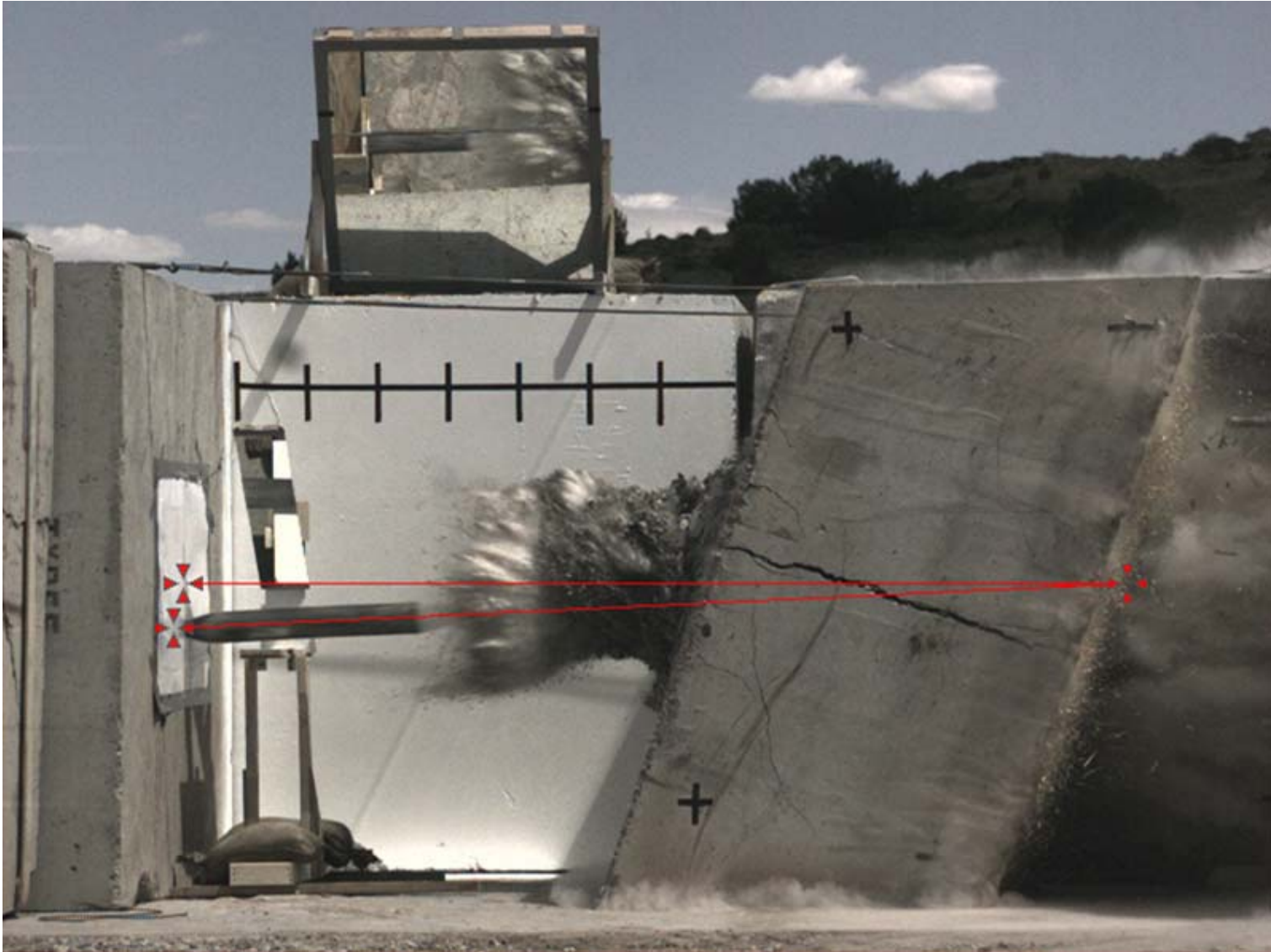# MD D Image from Phantom 1
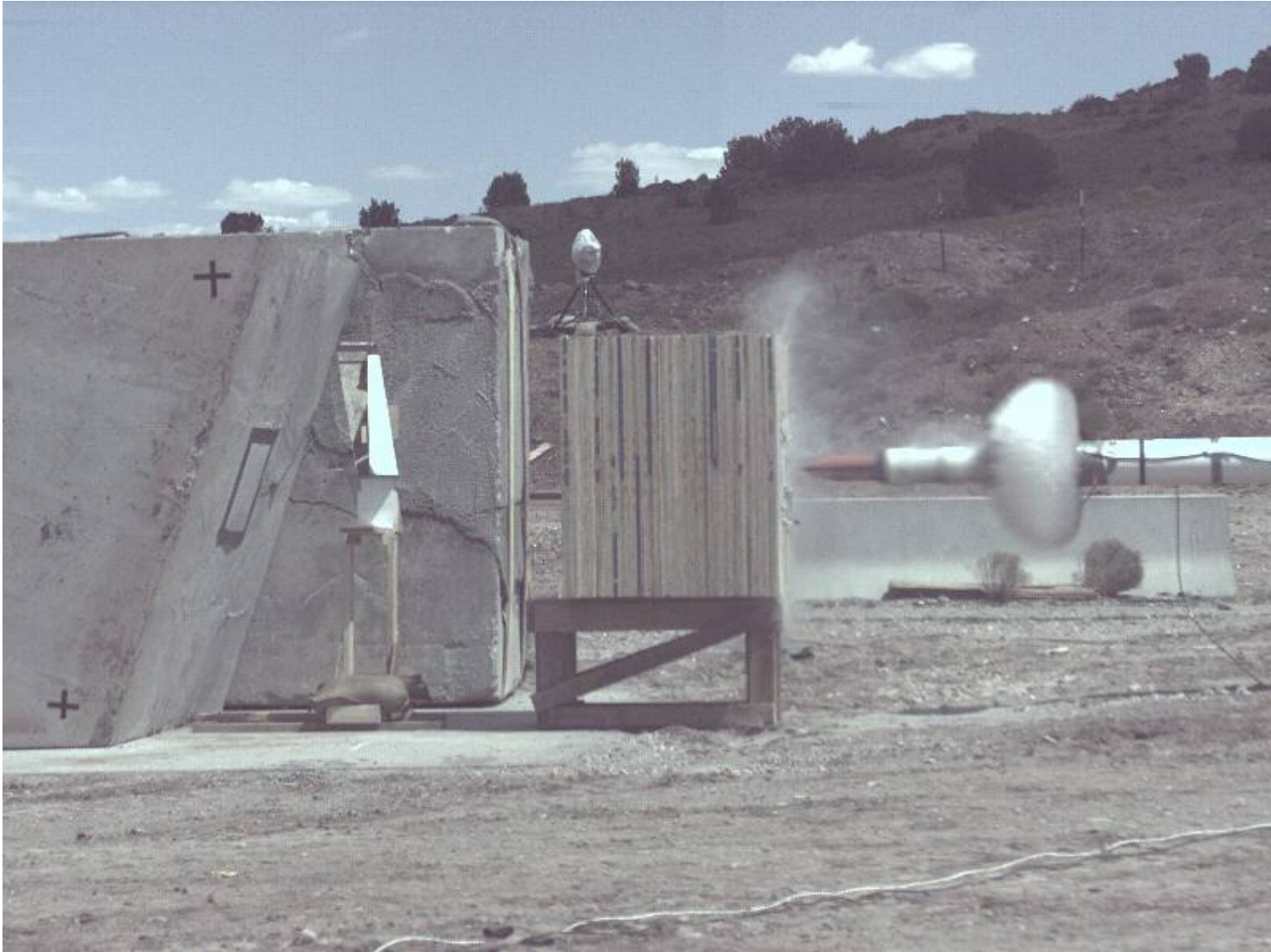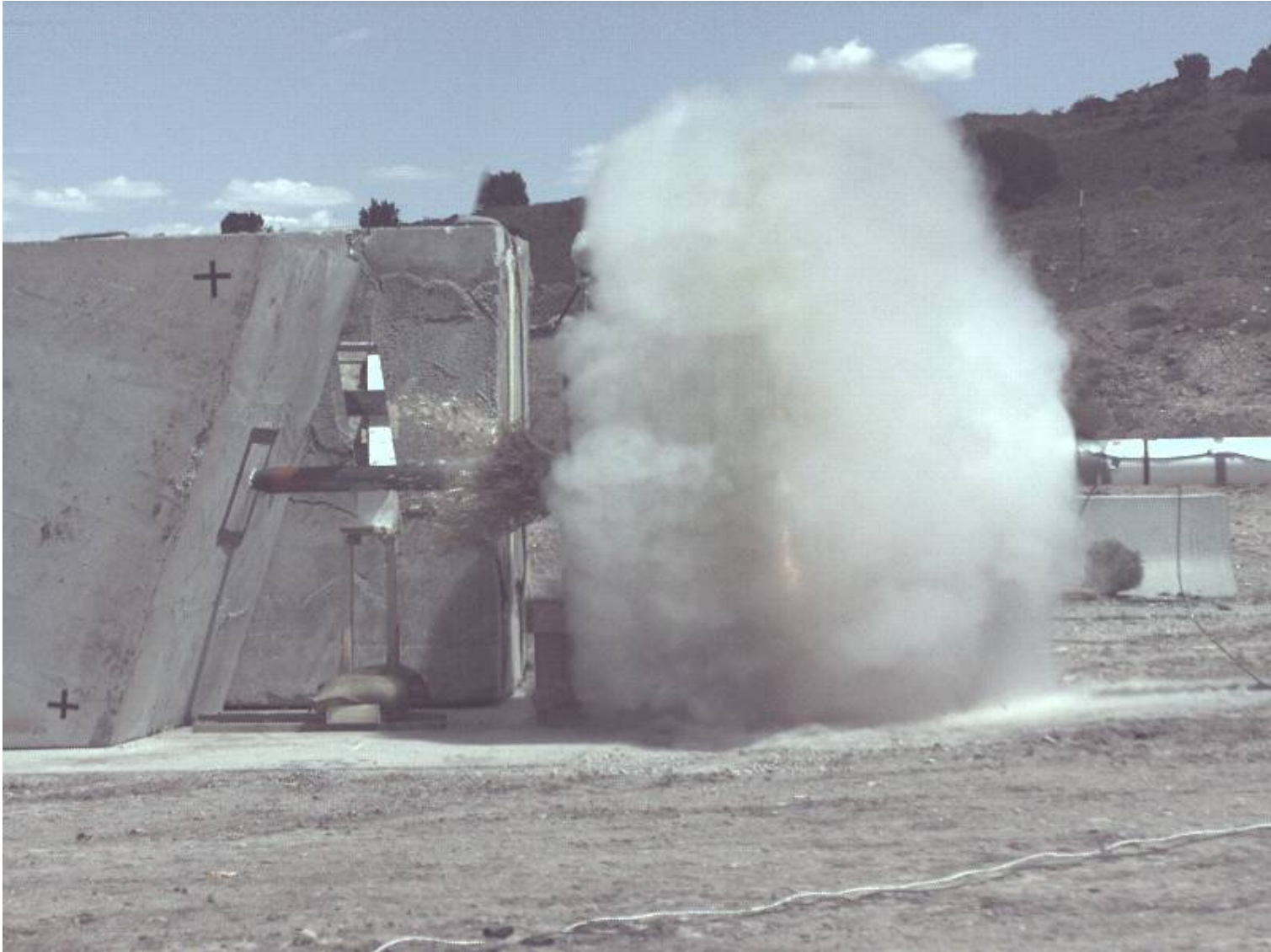
MD D Image from Phantom 1

MD D Image from Phantom 2

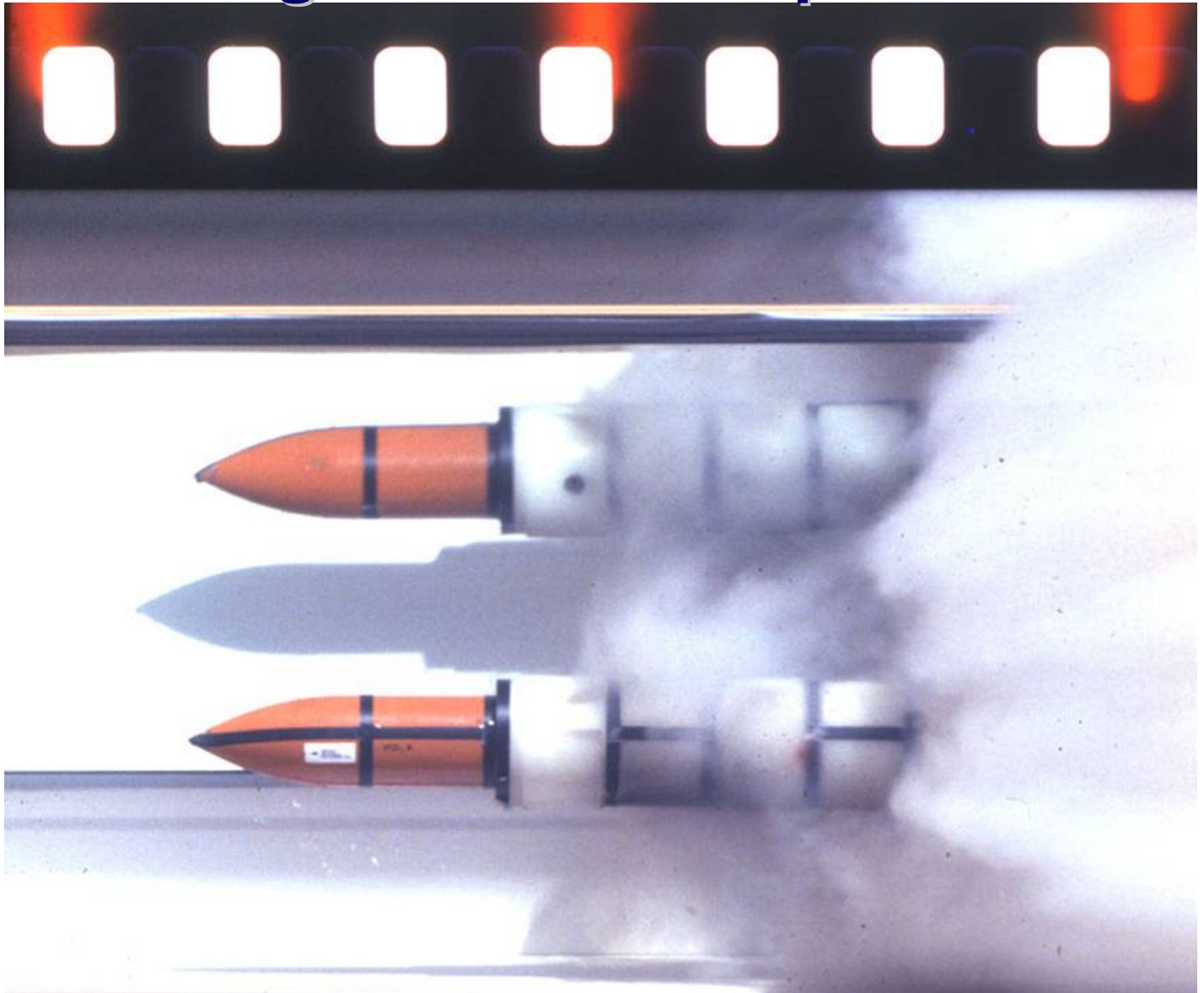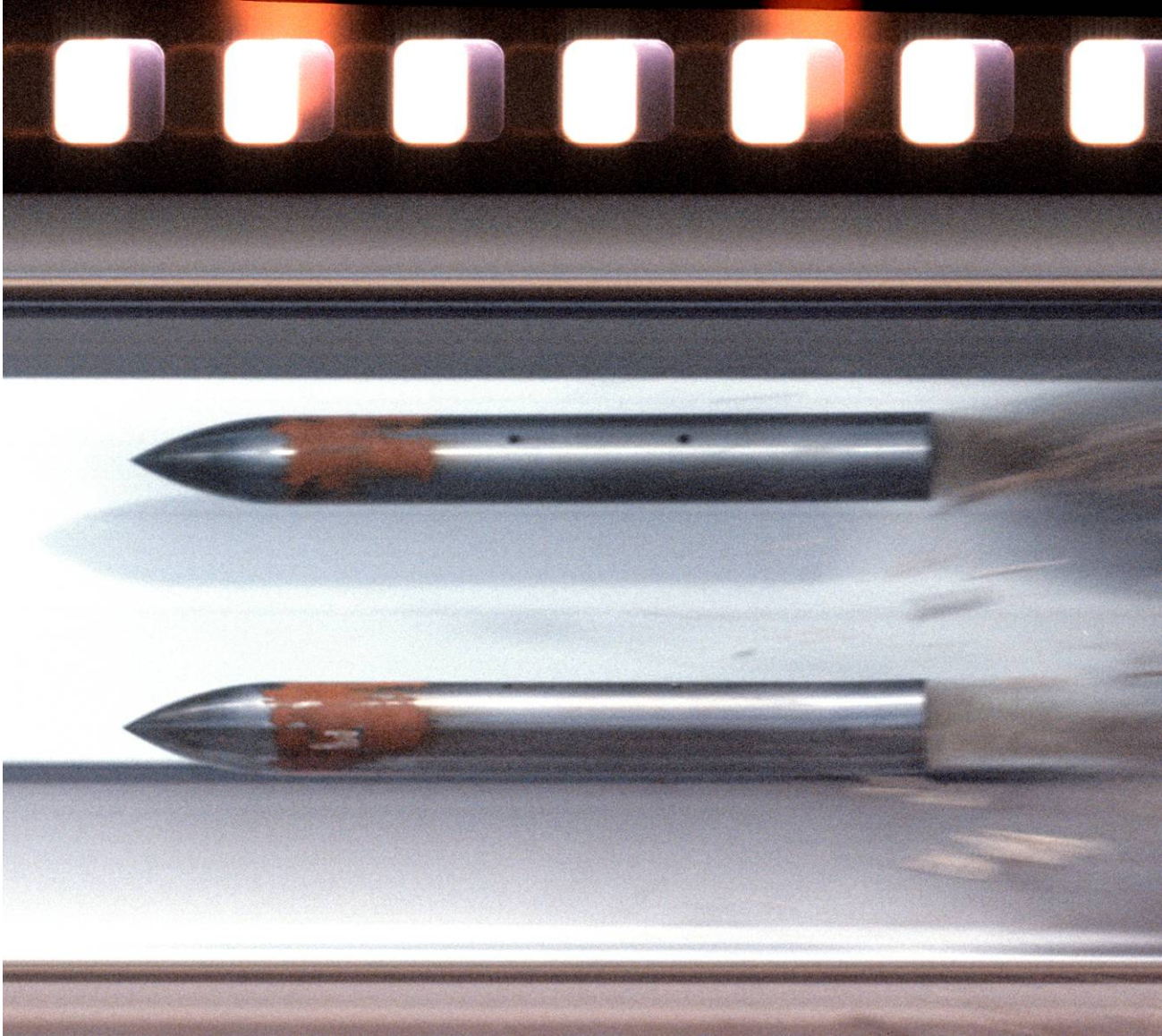# MD D Image from Phantom 2

MD D Image from Phantom 2
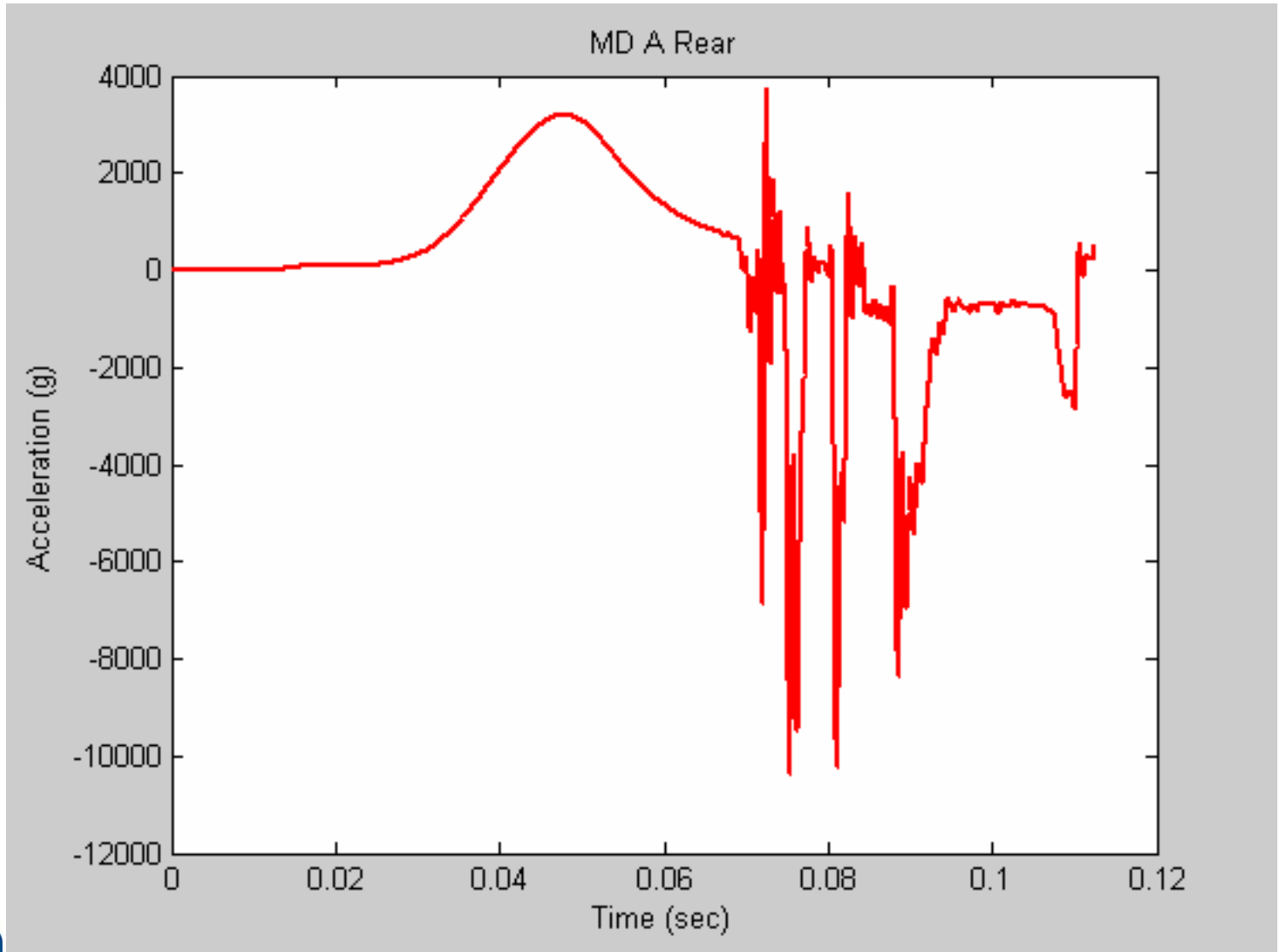
MD D Image from Phantom 2
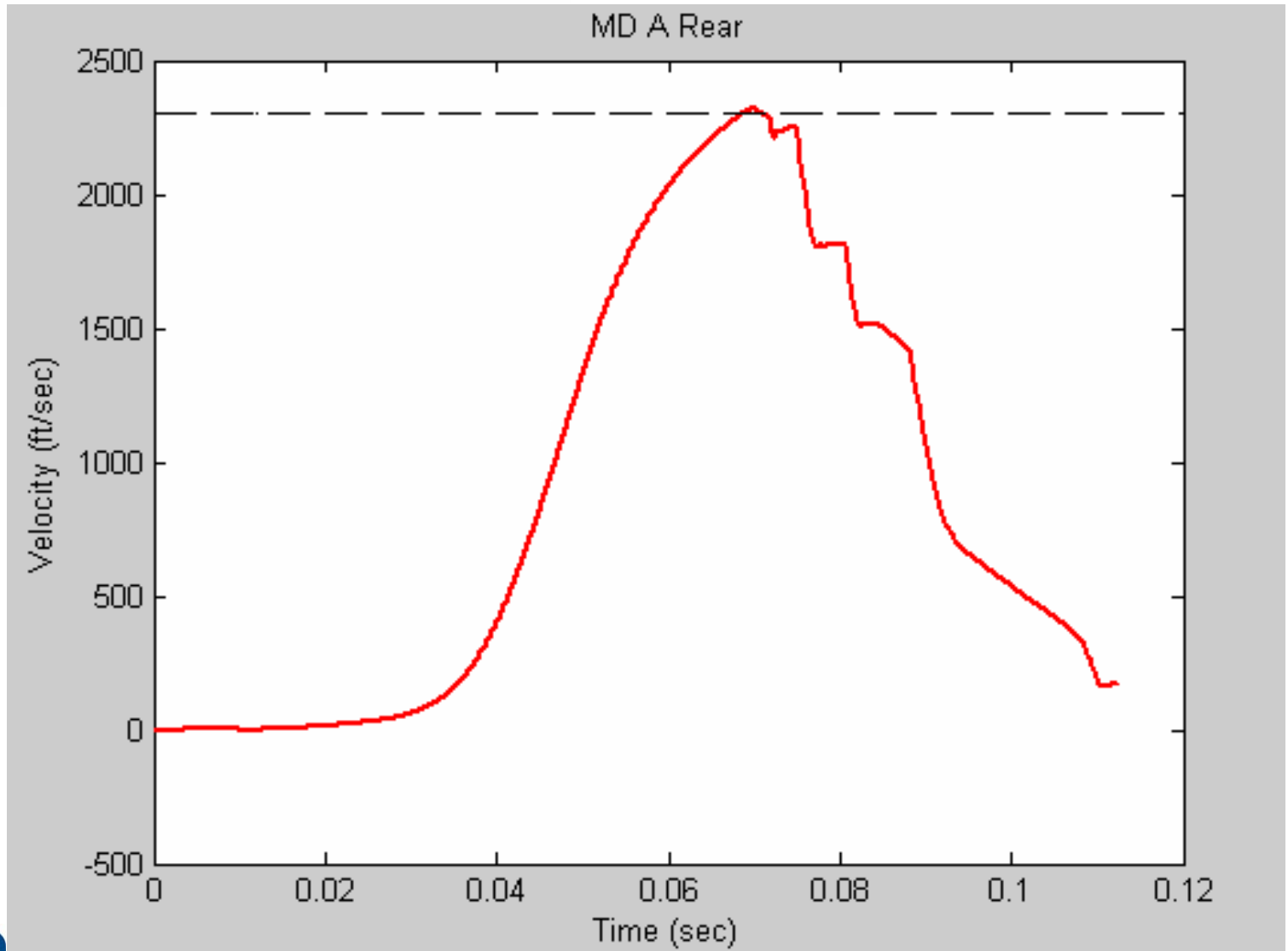
Orthogonal Image Motion Compensation
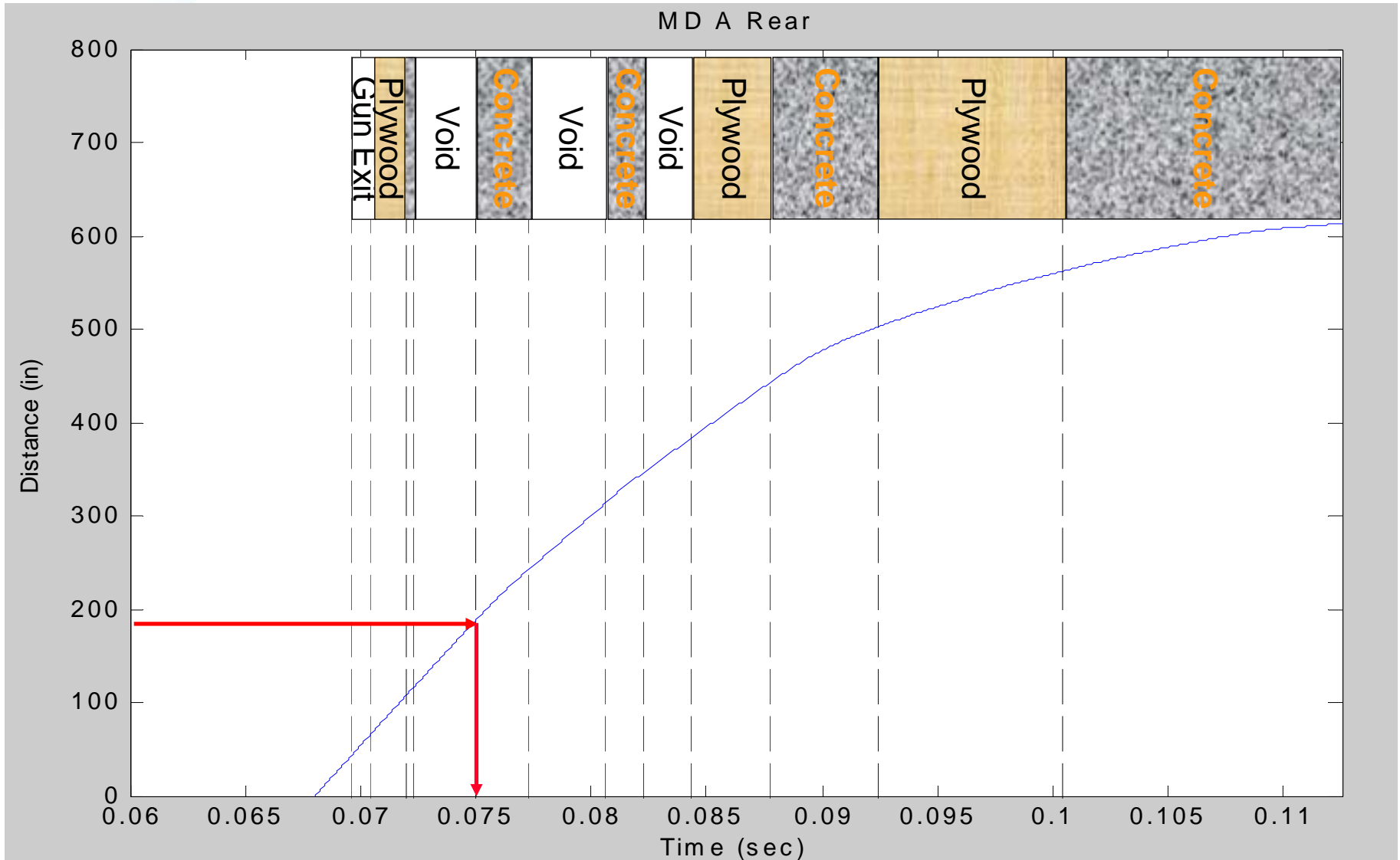
Orthogonal IMC after Penetration

MD A Rear Accelerometer Data

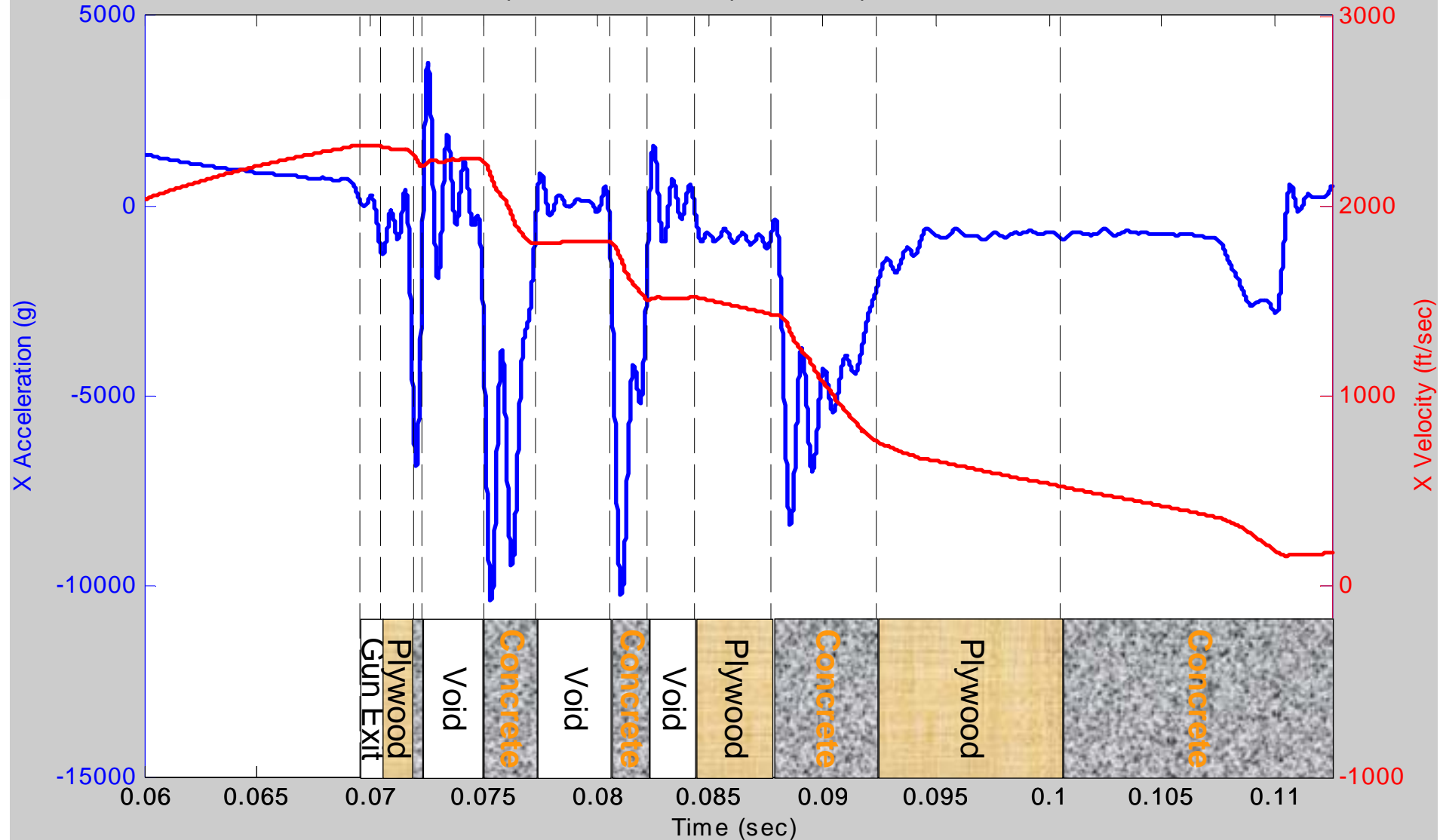# MD A Rear Accelerometer Data (Velocity)

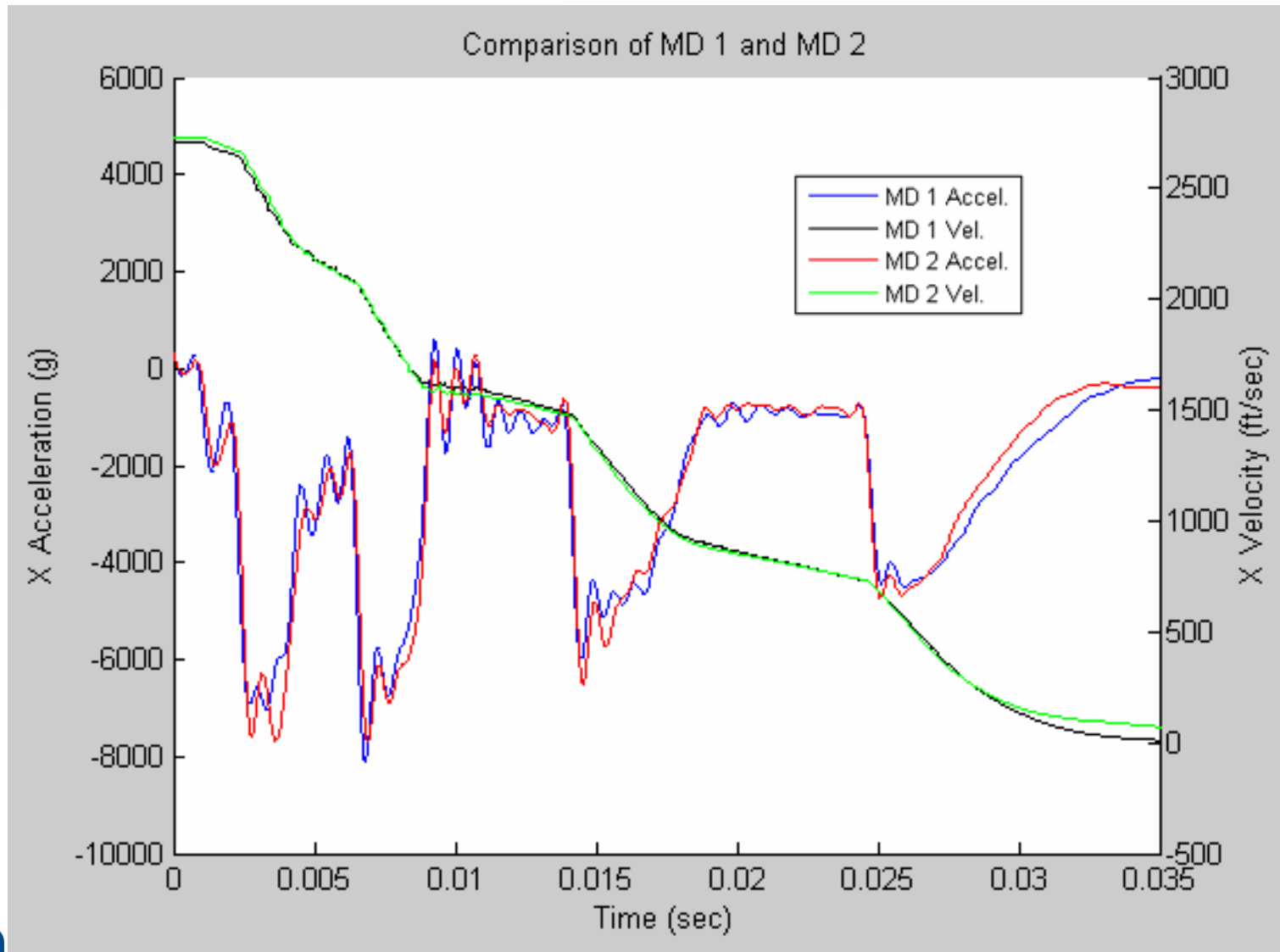# MD A Rear Accelerometer Data (Distance)

MD A Rear Accelerometer Data (Overlay)

MD A Rear, passband = 1000 rp = 0.1 stopband = 2000 rs = 40

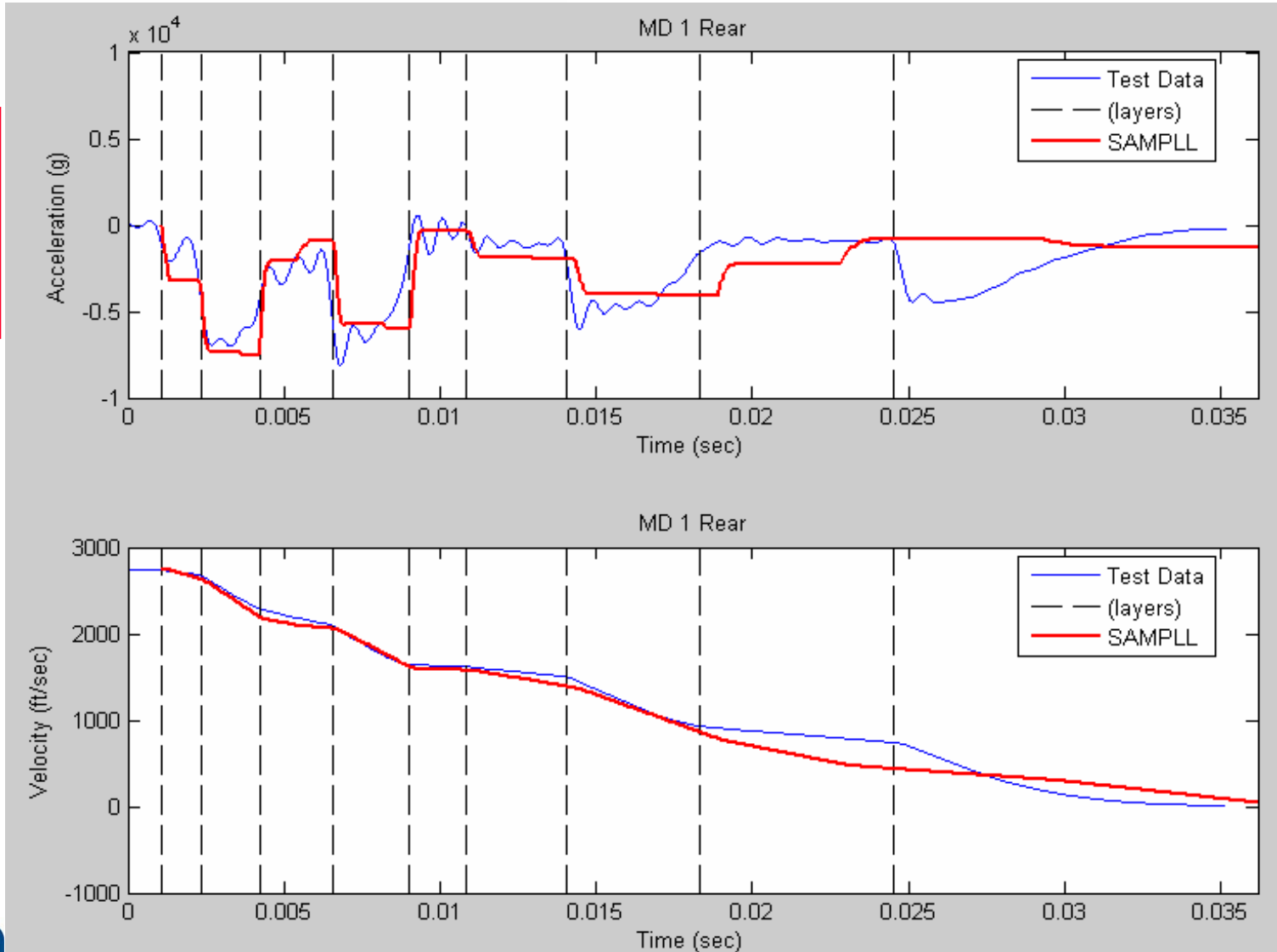# Comparison of MD 1 & 2 Accel and Vel Data
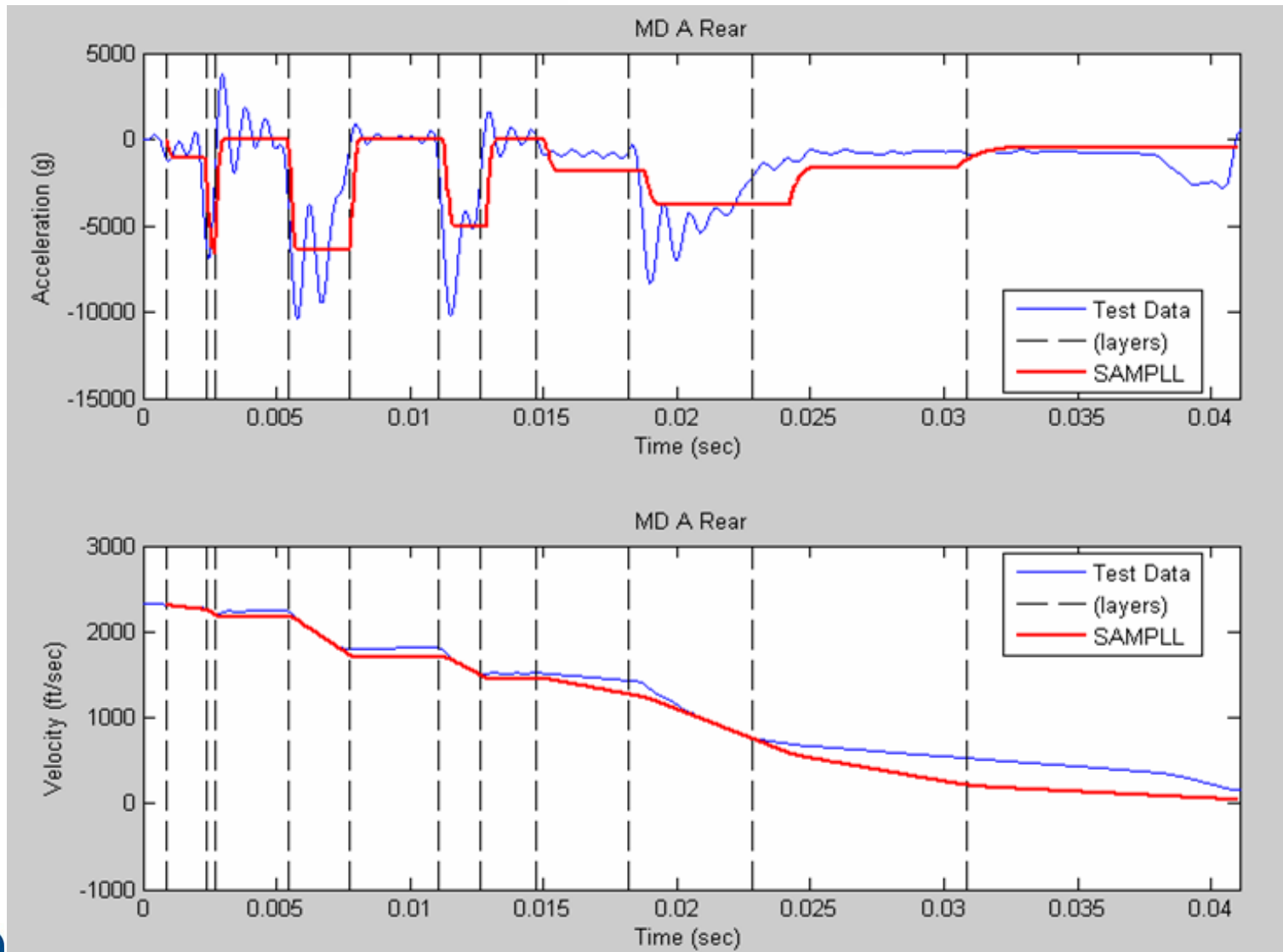
Penetrator Post Shot

Comparison of Accelerometer Data to SAMPLL
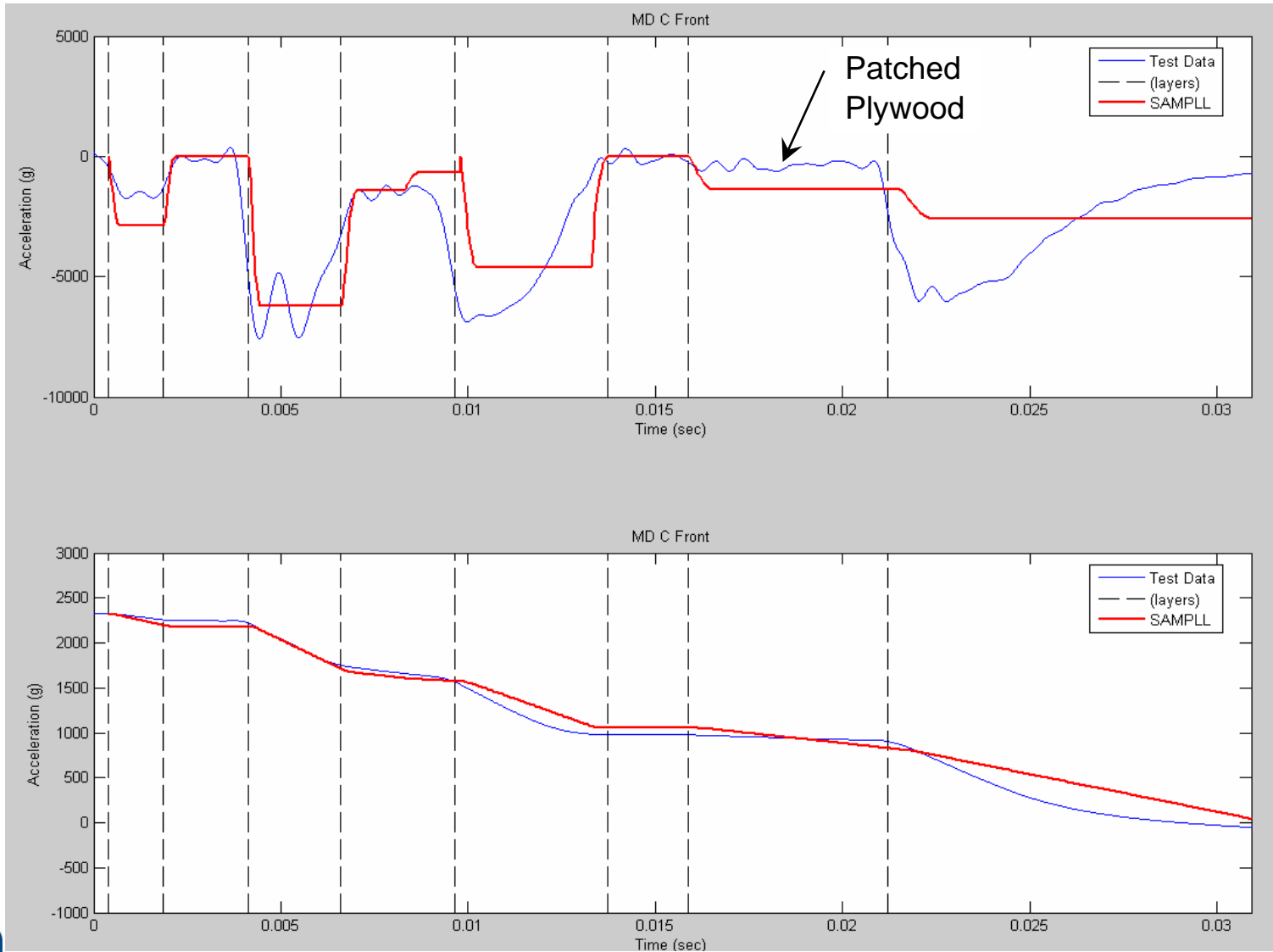
Final Resting Position of 38' within 8" of SAMPLL Prediction!

Expanding the Realm of Possibility

Comparison of Accelerometer Data to SAMPLL

Comparison of Accelerometer Data to SAMPLL

Expanding the Realm of Possibility

Comparison of Accelerometer Data to SAMPLL
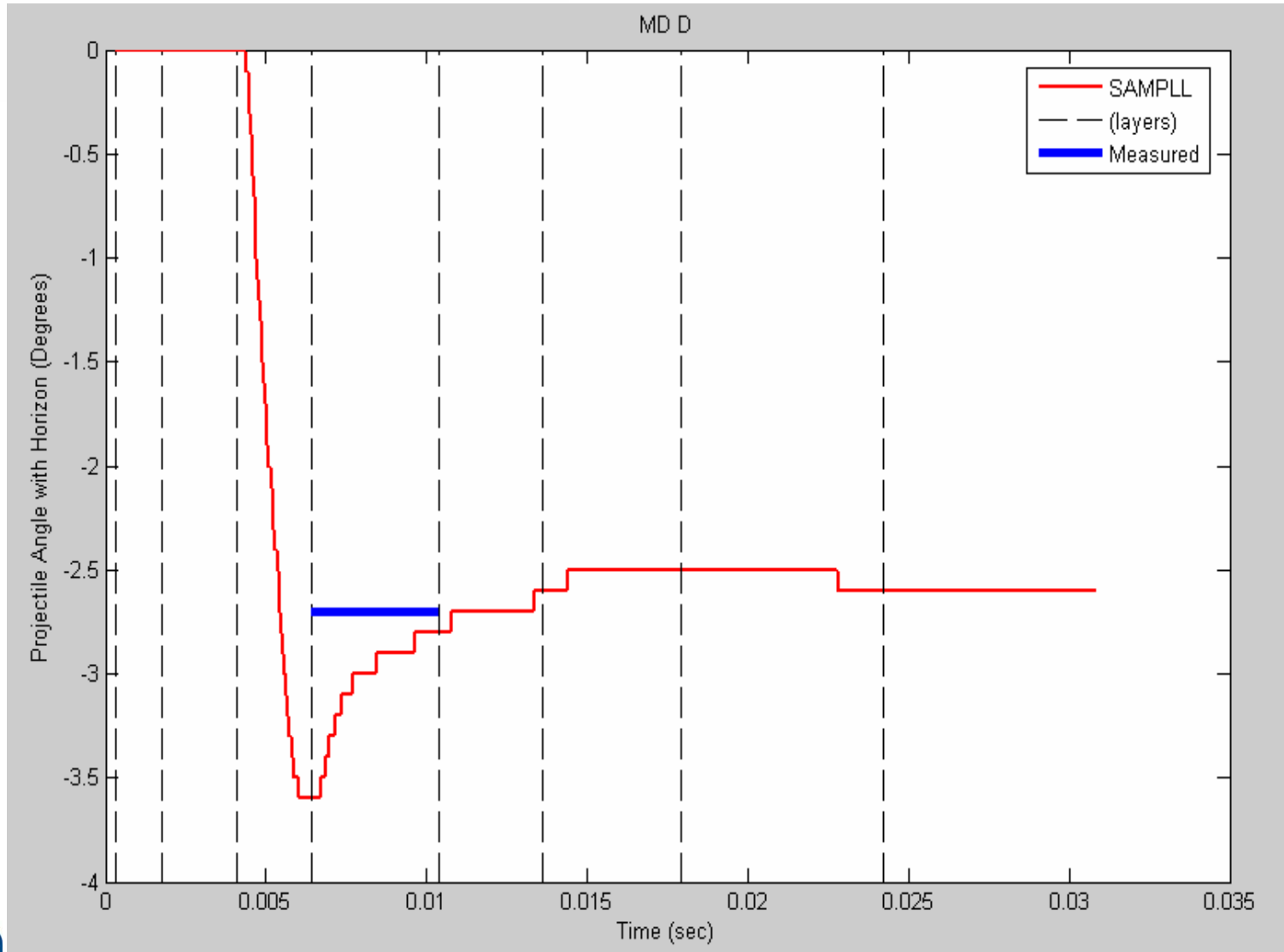
MD B Marked And Taped Sabot
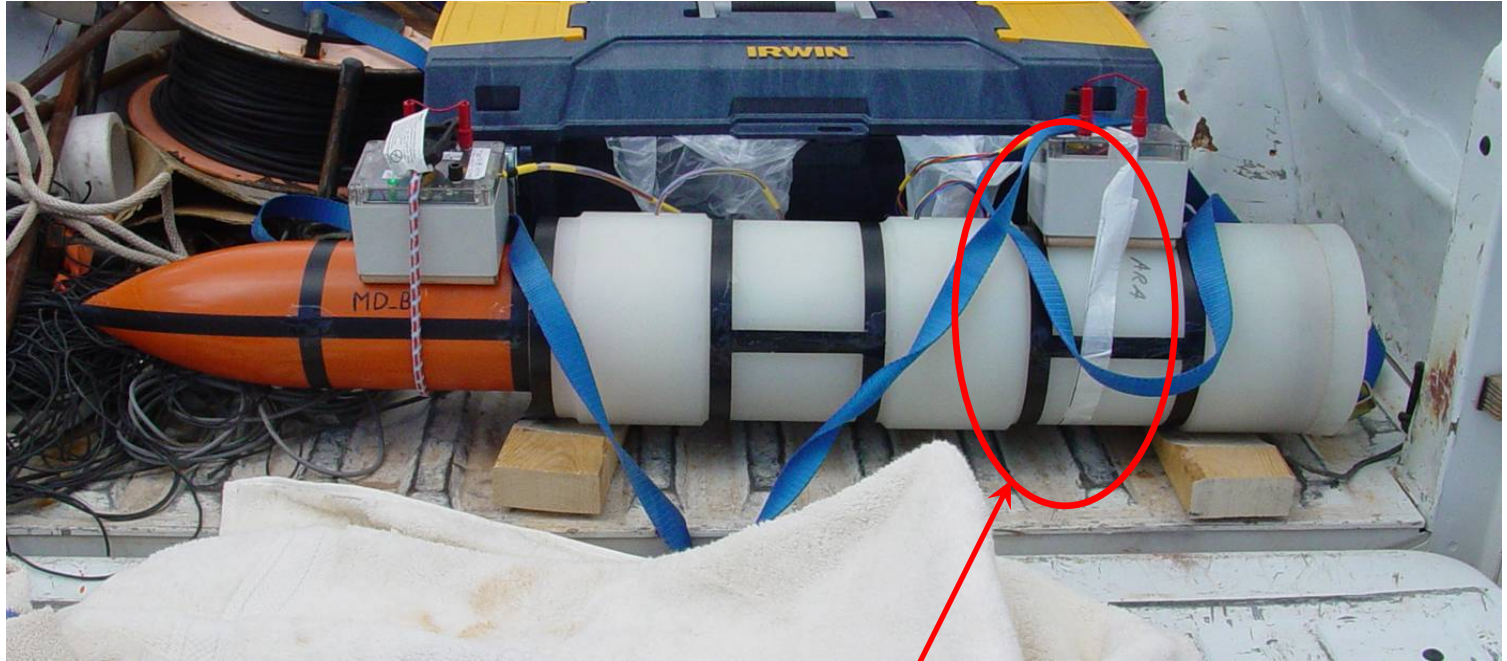
Initial Location
of Sabot Material
in Previous Image

MD B Marked And Taped Sabot Fragment, Turned Inside Out

Conclusions

- **Succeeded in collecting high-quality deceleration time-history data during high-speed multi-layered, multi-material penetration events**

- **Test data used to develop concrete model for LS-DYNA**

- **Excellent comparisons between LS-DYNA simulations and test data**

- **Excellent comparisons between SAMPLL pretest predictions and test data**

- **Successfully designed, engineered, and executed a complex test series, involving physics regimes at the edge of current understanding with a very high data recovery rate**