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ATC's Requirements Presented Challenges Requiring Innovative Solutions

Aberdeen Test Center (ATC) Required a New Scoring System for Bullets

- Limitations of Existing Scoring Systems
  - ➲ Acoustic Sensors
    - ➢ Acoustic Sensors Cannot Score Subsonic Rounds
    - ➢ Acoustic Sensors are not Sufficiently Accurate
    - ➢ Accuracy of Acoustic Sensors Affected by Humidity, Temperature, etc.
  - ➲ Paper Targets
    - ➢ Paper Targets are Inconvenient… May be Located Up to 4-km Downrange
    - ➢ Paper Targets Don't Associate the Rounds with the Holes in the Target

System Requirements:

- Accuracy on Order of +/- 1 mm
- 10- to 30-foot Active Scoring Area
- Bullet Size: 5.56 mm to Large Caliber
- Bullet Velocity: 75 - 1500 meters/sec
- Rate of Fire: 6000 rounds/min

3 Phase I SBIRs Awarded

- Orthogonal Line-Scan Cameras (Dynetics)
- Scanning Laser Beam
- Interferometry

Dynetics' Approach Chosen as Result of Superior Prototype Design, Performance and Excellent Prospects for Long-Term Development

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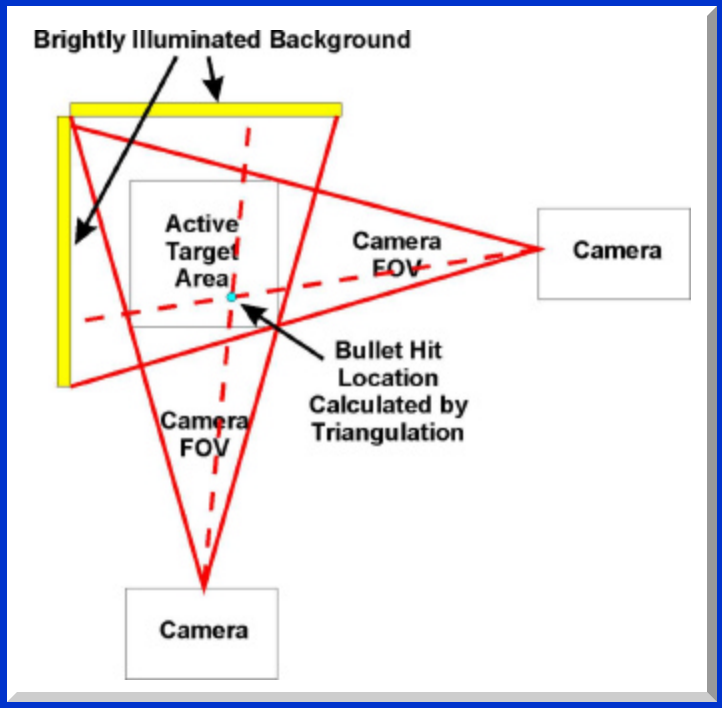
Our Approach Employed Two Line-Scan Cameras Along with High-Speed Signal Processing

The Dynetics Approach

High-Speed Cameras View the Bullets Against a Brightly Illuminated Background



Challenges:	System Development Implications:
High accuracy	High camera resolution (Analysis showed 2048 pixels)
Bullets are very fast	Very short frame exposure time and high frame rate
Bullets can be very small	Further aggravates exposure / frame rate requirements
Brief exposure requires bright illumination	Unusual illumination system required
Large active target area	Large structure size, compounds all the problems above

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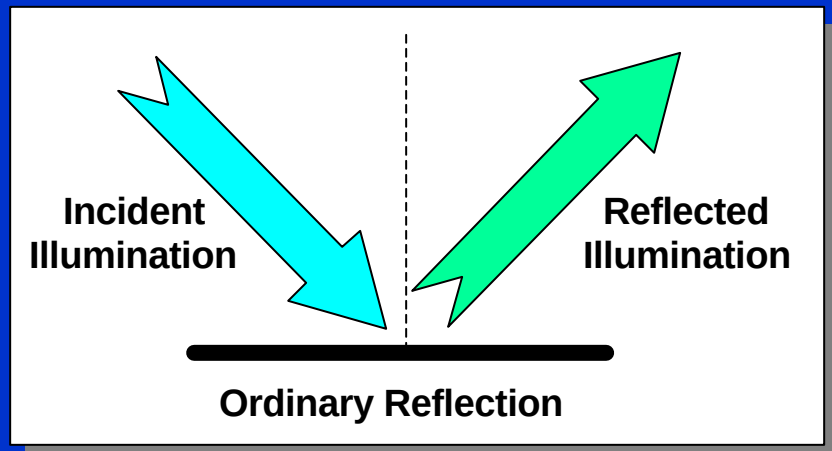
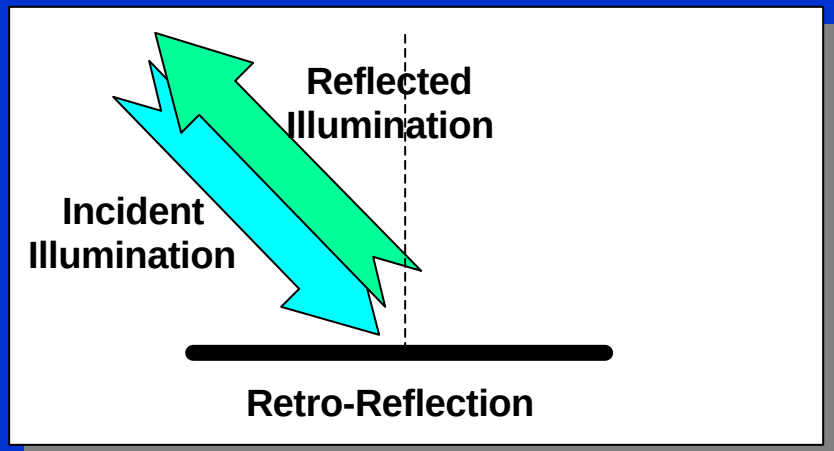
The First Requirement is An Extremely Bright Background





The Bright Background is Obtained by a Combination of:

- **Retro-Reflective Tape**
- **Bright, Incandescent Fan-Beam Illuminator Located Very Close to the Camera**

Material Used is Similar to Reflective Tape Used on Road Signs

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Fast Line-Scan Cameras Freeze Bullet Motion

Conventional Cameras Sense a 2-Dimensional Array of Light Levels (Black Squares)

Line-Scan Cameras Sense Light Levels From a Single Array of Detectors (Red Squares)

The Cameras We Used Operate at 16,000 Frames Per Second

Recent Experiments in Downsized Force Delivery Systems

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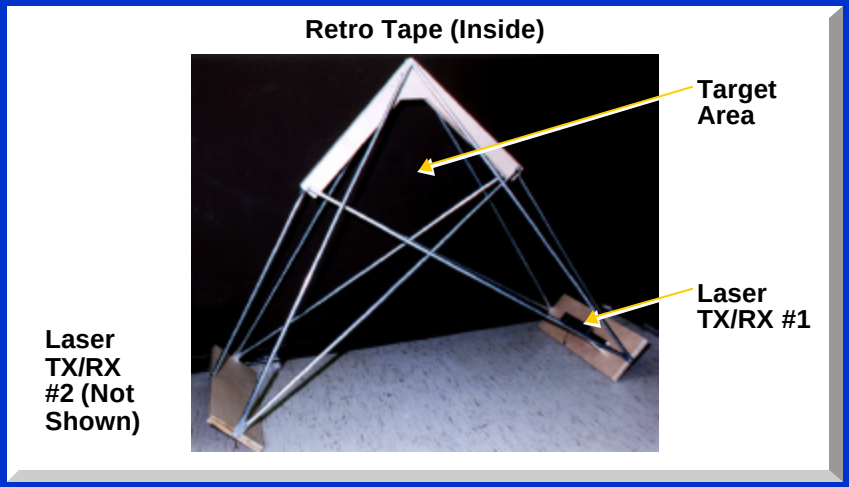
Phase I Prototype System



Phase I Prototype Device

- Target Structure Made of Plywood and Steel Conduit Tubing
- Utilized Laser Diode Fan-Beam Illuminator
- Analog 1024-pixel Line-Scan Camera
- Digital Oscilloscope Used for Data Capture
- PC Running Lab-View Used to Process Data
- 1.5 ft x 1.5 ft active scoring area
- 6 ft x 6 ft Overall Size

Phase I Result

Prototype worked well enough to demonstrate the principle-of-operation. AND, it led to the award of a Phase II SBIR contract.

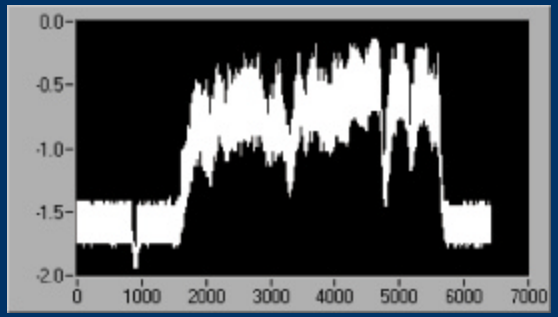
Phase I Limitation

It was difficult to scale to 10 ft while maintaining portability. Laser speckle was also a problem, and the volume of data had to be reduced to a manageable amount.

Phase II Approach

We proved that illuminating retroreflective tape from the camera location would yield a sufficiently bright bullet image!

Typical Camera Data



Speckle Consumes Much of the Camera's Dynamic Range

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Phase II Design and Development Demanded a Balanced Solution and More Innovation

A Balanced Solution *Was Required*

- A Structure had to be Devised That was Portable by Two Men
- An Intelligent Frame Grabber Capable of Recognizing Bullets was Required to Pare the Data Volume Down to a Manageable Level; *None was Available*
- A Non-Coherent, Very Bright, Wide-Angle Fan Beam Illuminator was Required; *None was Available*
- Data Processing and Display of Results had to Appear to be Instantaneous to the Operator
- The System had to be Accurate and Easy to Use

Dynetics' Approach

- We Searched the Literature and Vendors for Information and Components
- We Consulted with a Number of Experts in Several Fields
- We Designed and Conducted Analysis and Simulations
- We Conducted Numerous Experiments and Measurements; the Results were Fed Back into the Analysis and Simulations to Quantify the Value of Ideas, Methods, Components, etc.
- We Kept Our Customer Appraised of All Our Activities and Results
- We Consulted with Our Customer to be Sure that Our Goals were Always Synchronized

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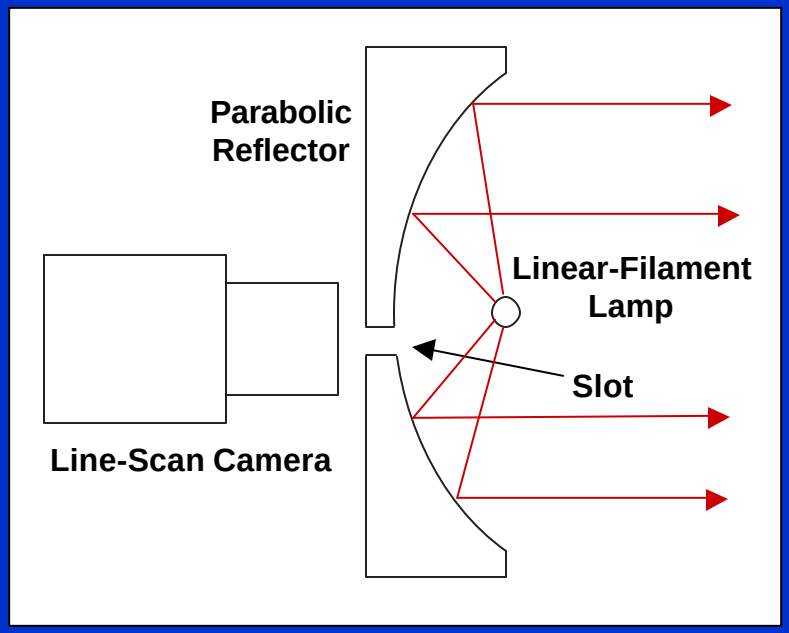
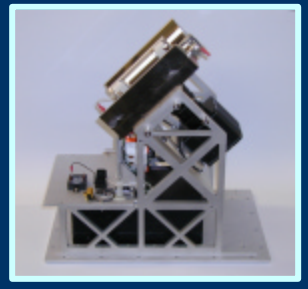
The Non-Coherent Illumination System



- Aluminum Mirror; Highly Polished and Nickel-Plated
- Provides 2º x 120º Fan Beam
- Wide Illumination Allows Wide Camera FOV, Allowing Size to be Greatly Reduced
- Camera Looks Through Offset Slot in Mirror
- Cylindrical Design Completely Removes Image of Lamp's Filament Supports and Helical Structure
- Metal Mirror Protects Camera from Lamp's Heat
- Plenty of Illumination, Even for 30 ft System

Top View Showing Camera and Reflector

Front View Showing Reflector and Lamp



Side View Showing Structure, Camera, Reflector, and Pwr. Supply

Completed Optical Unit

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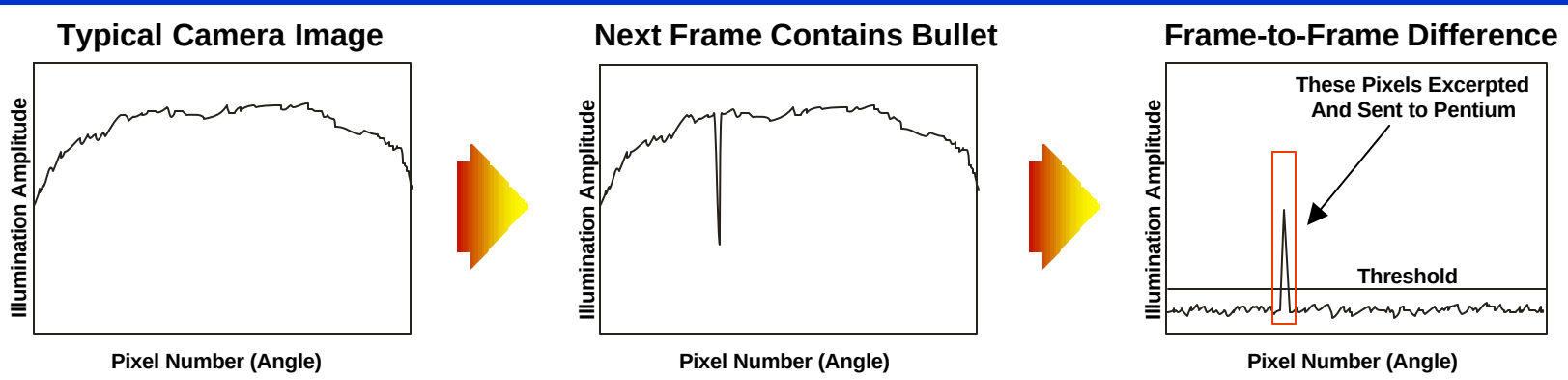
Custom, Frame-Grabber



Required Functionality

- Capture Line of Data
- Compute Frame-to-Frame Difference, Pixel-by-Pixel
- Compare All Pixel Differences to Threshold
- If Any Difference Exceeds Threshold, "Snip Out" that Region of Data; Send Data Along with Its Location to Computer
- All this Must Happen at 32 MEGApixels/sec

Unfortunately, that Capability was Not Commercially Available

We Built Our Own!

- Procured COTS XILINX FPGA board to fit into a standard PC
- Programmed required functionality into FPGA (with room to spare)
- Designed and fabricated daughter board to fit onto FPGA card, providing interface to camera

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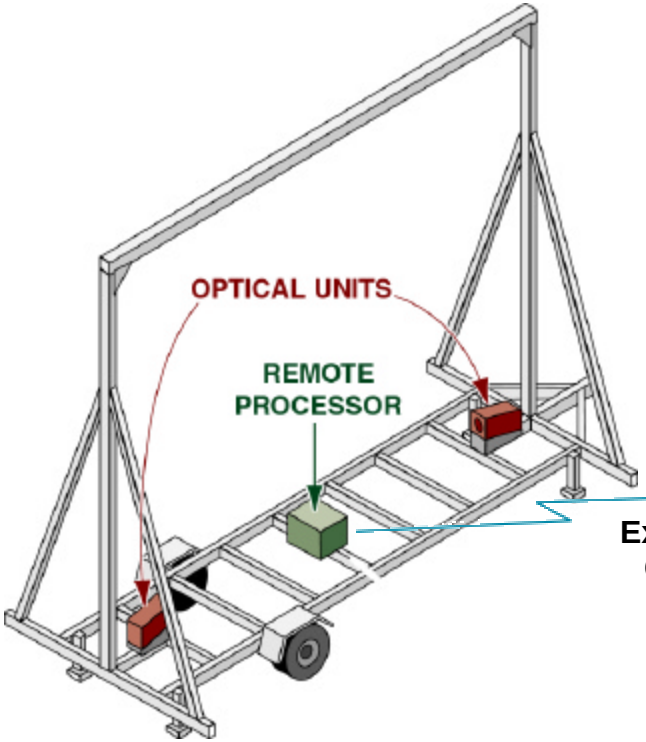
Opti-Score Subsystem Layout



VIRTUAL TARGET

- Projectile Detection
- Centroid Calculation

Exchange Test Parameters, Commands and Data

- User Interface
  - Test Description Input
  - Test Result Display
  - Test Control

SHOOTER'S STATION

- Coordinate Calculation
- Statistics Calculation
- Output File Generation
- Test-range Computer Communication

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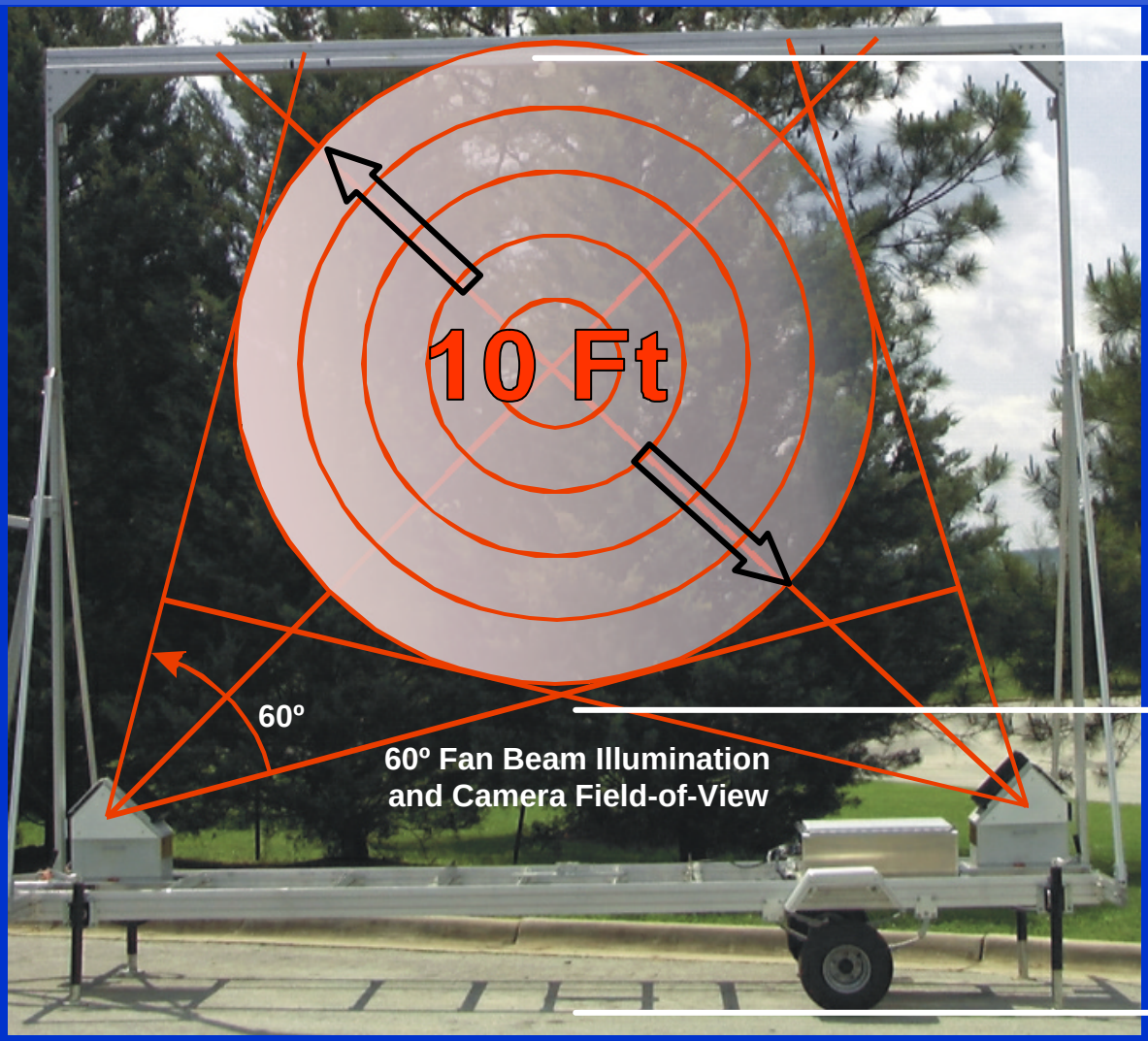
Opti-Score Active Target Area



Increasing the Fan-Beam Angle from 30º to 60º Greatly Reduced Size

Portability was Achieved Through the Use of an Aluminum Trailer

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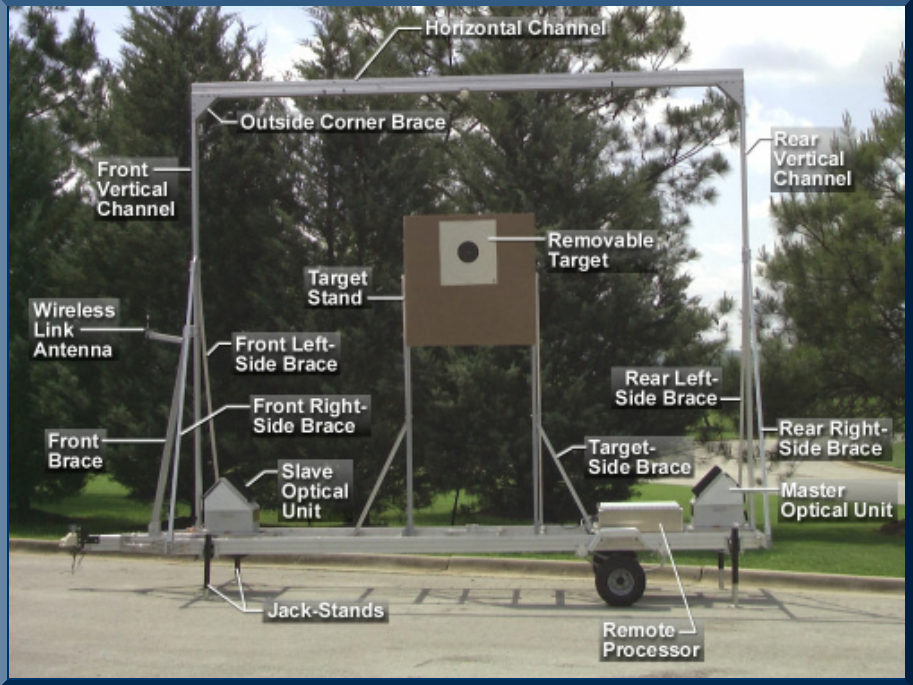
Opti-Score Components

Opti-Score Virtual Target System



Optical Unit (2 Required)

RF Data Link

Operator's Computer

Opti-Score Operator Interface Provides Full System Control, Data Processing, and Display

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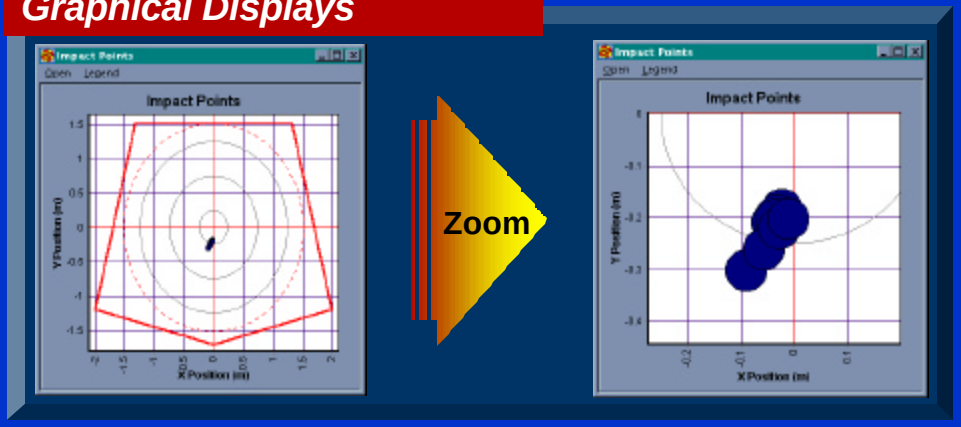
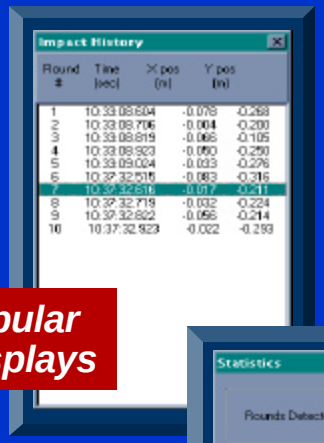
Excellence in Testing ATC Aberdeen Test Center

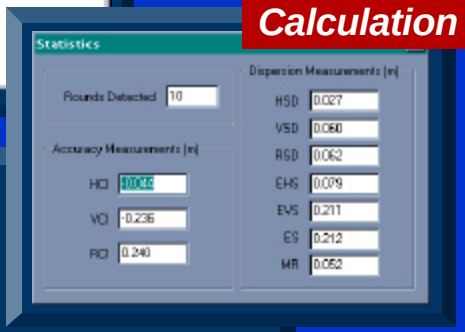
Graphical Displays



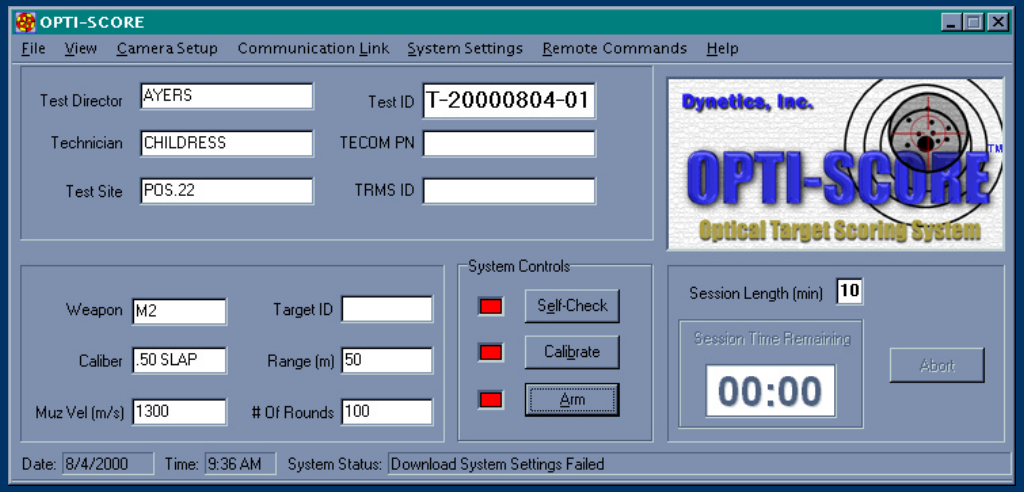
Tabular Displays



Automatic Statistics Calculation



Operator's Control Window



- Remote Target Control
- Data Recording and Access
- System Diagnostics

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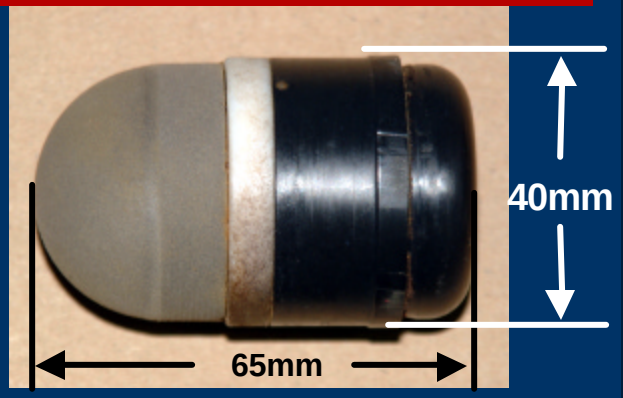
Opti-Score Imaging by Post-Processing

Photo: 40mm Sponge Round

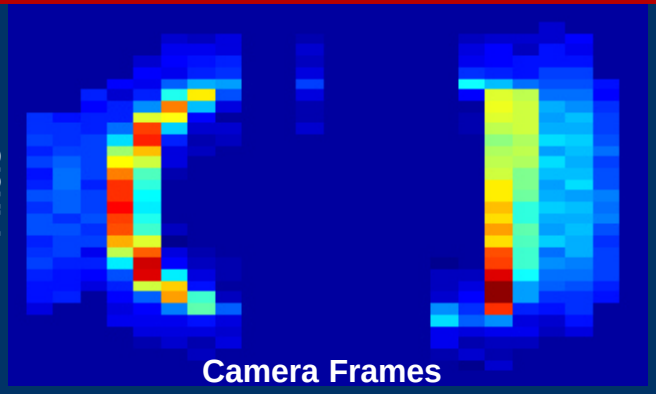


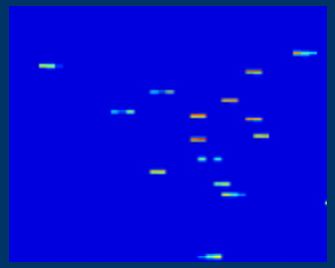
Data Acquired During Firing was Post-processed to Yield Time History (or *Image*) of Projectile Passage Through the Target

Opti-Score Imaging Properties:

- Image Shows Shape of the Projectile Along with its Angle-of-Attack
- Image Allows Velocity Measurement Under Certain Circumstances
- Differential Appearance of Image is Due to Data Transfer Implementation. Can Easily be Changed to Meet Needs of Specific Users

Corresponding Opti-Score Image





Multi-Ball Shotgun Image

Imaging Allows the Patterns of Munitions to be Observed

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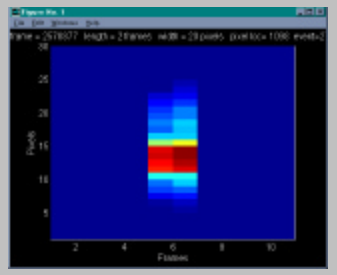
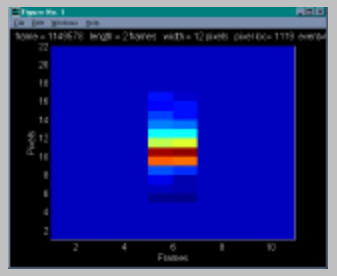
Images of Various Objects

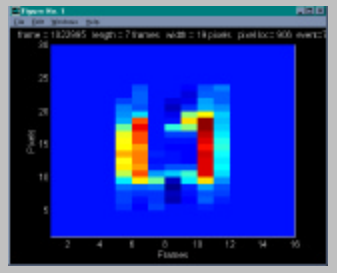
Excellence in Testing
ATC
Aberdeen Test Center



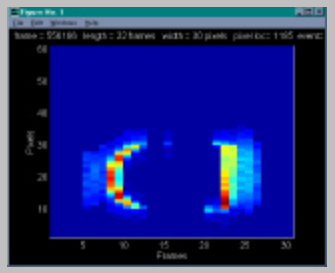
SLAP
.32 cal
1100 m/s



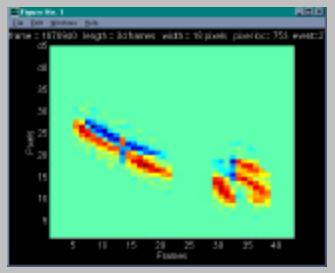
5.56 mm
900 m/s

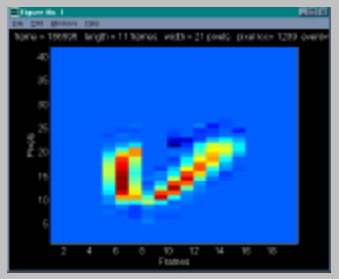


Less-Lethal
Fin Stabilized
(12 Ga.)



40 mm Less-Lethal
Sponge, 100 m/s





INSECTS:
Automatically Filtered
Out of Reported Data

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Opti-Score System Development Summary

Opti-Score Provides Aberdeen Test Center with Capabilities Well Beyond those of Pre-Existing Scoring Systems

Opti-Score:

- Is More Accurate than Pre-Existing Systems
- Is Much Easier to Use than Pre-Existing Systems
- Scores Subsonic Rounds; Previous Acoustic Systems did Not
- Scores Any Round Currently in the Arsenal
- Accommodates All Rates of Fire

The Customer is Pursuing Funding for Additional 30-foot Units

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Where Do We Go From Here?

Excellence in Testing
ATC
Aberdeen Test Center

Training

Metrology

Large Caliber
Marksmanship
Aircraft Gunnery
Law Enforcement

Recreational Indoor Ranges

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Current Status of Opti-Score

10 Foot Prototype System has been Delivered to ATC and is Performing Well

Additional Engineering is Needed:

- The Cameras Used on Prototype are No Longer Available. Suitable Replacements Are Available, but a New Electrical Interface is Required
- The Cost of Future Systems can be Greatly Reduced by Redesigning Complex Machined Components Inside the Optical Units
- 30 Foot Systems Require Much Larger Structures to Support Retro-reflective Tape. Mechanical Design for that Structure is Required
- Current Remote Processor can be Relocated Inside One of the Optical Units to Reduce Cost