Azimuthal Multipliers

Characterizing Arena Fragmentation

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Azimuthal Multipliers

Agenda

- Objective
- Background
- Improved Process Benefits
- Definition of Azimuthal Multipliers
- 1500 lb Penetrator Analysis Analysis
- Error/Uncertainty Approximations
- Concurrent Improvements
- Summary

Azimuthal Multipliers

Definition

- **Azimuthal Multipliers – computer-based, high-fidelity methodology for extrapolating fragmentation for lethality analysis, collateral damage estimates, and safe escape calculations.**

Azimuthal Multipliers

Objectives

- **Objectives**
  - **Objective 1: Collect and evaluate blast and fragmentation characteristics of warheads detonated within a specially constructed and instrumented arena.**
  - **Objective 2: Improve arena data reduction techniques to allow for diverse arena designs and improved fragment characterizations.**

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Arena Background

- **Current Test Procedures in the Joint Munitions Effectiveness Manual**
  - 2-3 Horizontal Arena Tests
  - 1-2 Vertical Arena Tests
- **Reliable data crucial to fielding hundreds of weapons**
  - Lethality
  - Collateral Damage
  - Safe Escape
- **Test Instrumentation and Equipment**
  - Fiberboard Collection Bundles
  - Ricochet Barrier
  - Witness panel is placed at test center to prevent cratering
  - Arrays of Pressure Transducers
  - Fragment Protection Poles
  - First Light Indicators
  - Time of Arrival Sensors
  - Velocity Screens or Flash Panels

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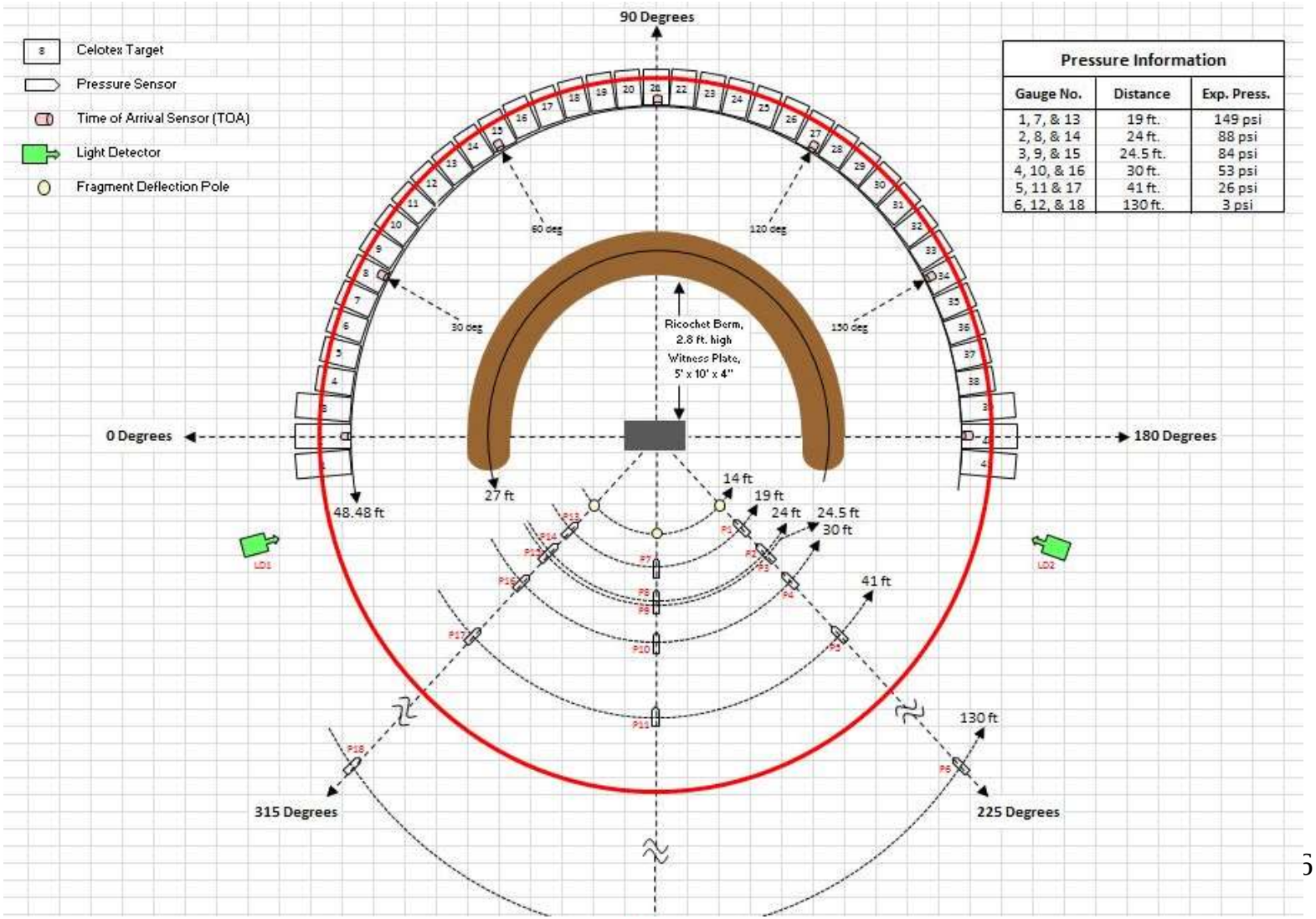
Arena Background



Pressure Information		
Gauge No.	Distance	Exp. Press.
1, 7, & 13	19 ft.	149 psi
2, 8, & 14	24 ft.	88 psi
3, 9, & 15	24.5 ft.	84 psi
4, 10, & 16	30 ft.	53 psi
5, 11 & 17	41 ft.	26 psi
6, 12, & 18	130 ft.	3 psi

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Arena Background

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Arena Background

- **Pressure Data**
  - Peak Pressure
  - Time of Arrival
  - Positive Phase Impulse
  - Positive Phase Duration
- **Fragment Data Analysis**
  - Velocity screens are used to collect average fragment velocity within 5-degree polar zones
  - A small but representative azimuth is sampled in a horizontal arena test
    - **N, Number of Fragments (Average number of fragments by polar zone and weight group)**
    - **M, Fragment Mass (Average fragment mass by polar zone and weight group)**
    - Fragment Shape
    - Fragment Location
    - Fragment Type
  - Zone multipliers (Z) are used to mathematically extrapolate the data around a 360-deg Sphere

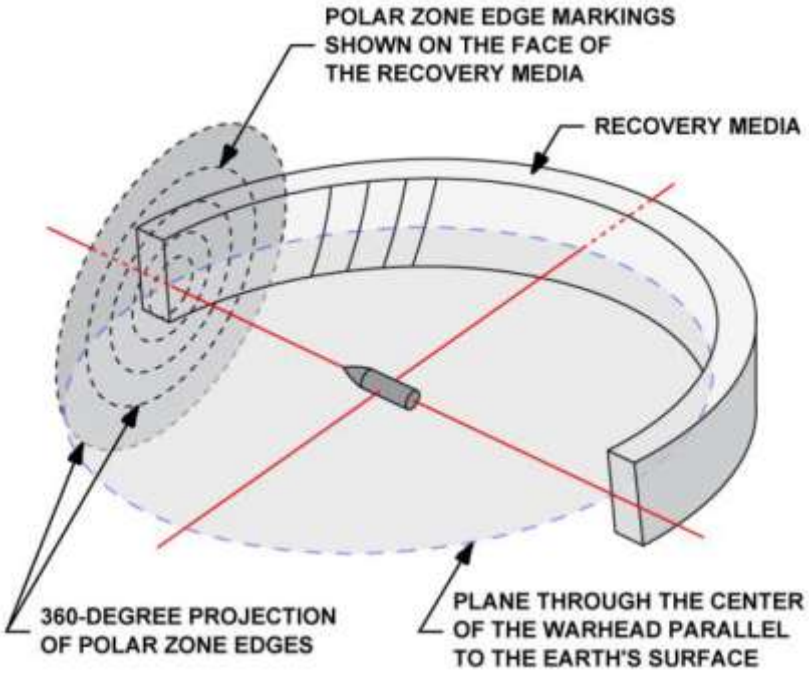
Azimuthal Multipliers

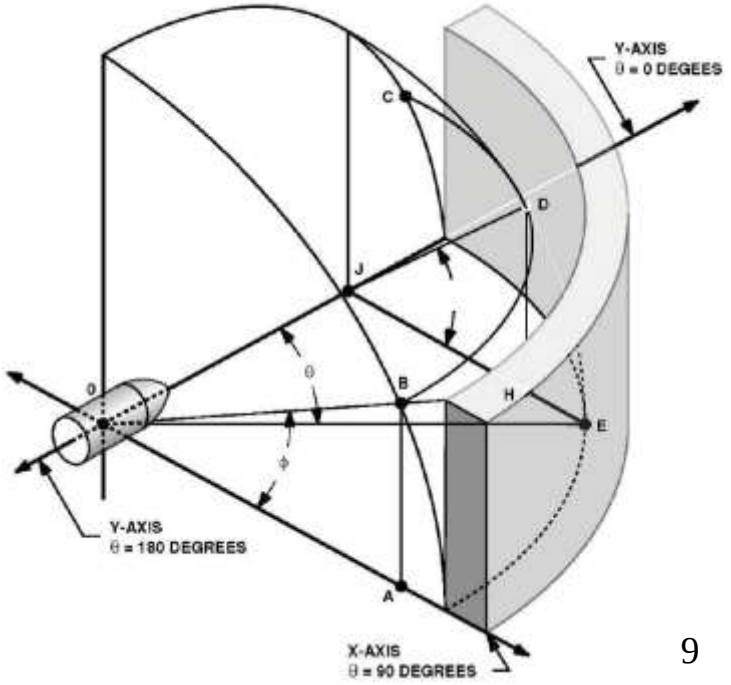
Arena Background

– Zone multipliers (Z) are used to mathematically extrapolate the data around a 360-deg Sphere

$$Z_j = \frac{A_{PZj}}{A_{wj}}$$

$$N_{ej} = Z_j N_j$$





Azimuthal Multipliers

Arena Background

- **Assumptions**
  - The inside surface of the recovery bundles is a smooth cylinder.
  - Fragments that impact the bundle face are collected.
  - All fragments emanate from the center of the warhead, which is also the center of the polar sphere.
  - Fragmentation is uniformly distributed about the longitudinal axis of the warhead of any given polar zone.
  - All fragment trajectories are straight lines.

- **Eliminate assumptions to improve accuracy, decrease uncertainty, and optimize arena designs**

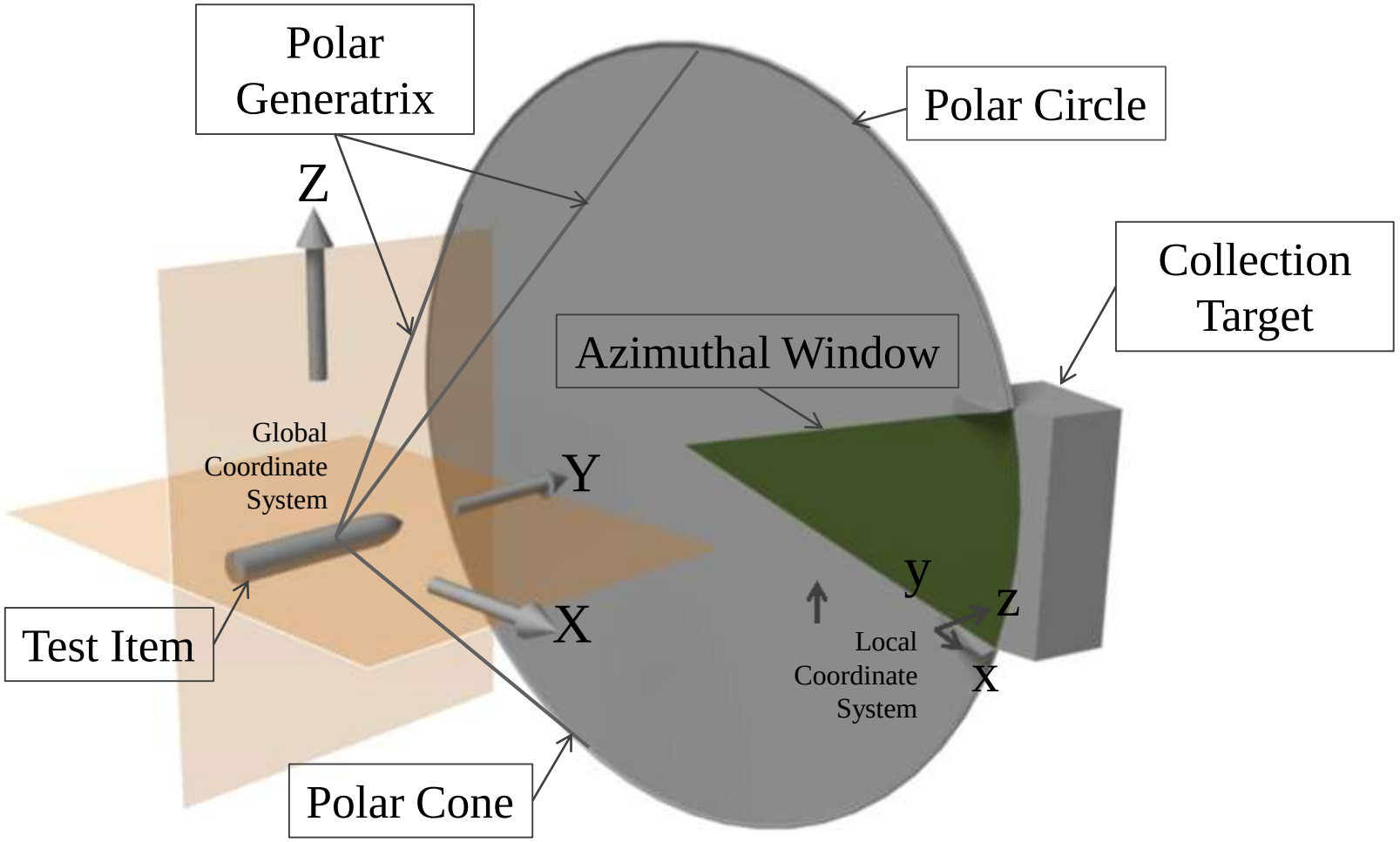
Azimuthal Multipliers

Process Benefits

- **One-time Software Change**
- **Improved Analysis**
  - Highlights fragment concentrations
  - Highlights one-of-a-kind fragments
  - Improved Lethality, Collateral Damage, and Safe Escape Calculations
- **Greater Accuracy and Precision**
  - Eliminate inaccuracies and uncertainties from several sources
    - **Essential for more directional weapons under development**
  - Numerical instead of categorical results are better for statistical analysis
    - **Round to round variations**
    - **Weapon to weapon comparisons**
- **Additional Arena Geometries**
  - Additional instrumentation
  - Flexibility for unusual test items
  - Fire breaks
  - Minimize wedge shaped gaps
- **Optimize Tests**
  - Minimize vertical arena tests ($225k)
  - Minimize collection material ($500k)
- **Concurrent Improvements**
  - Stereographic video analysis
  - 3D Z-data Files

Azimuthal Multipliers

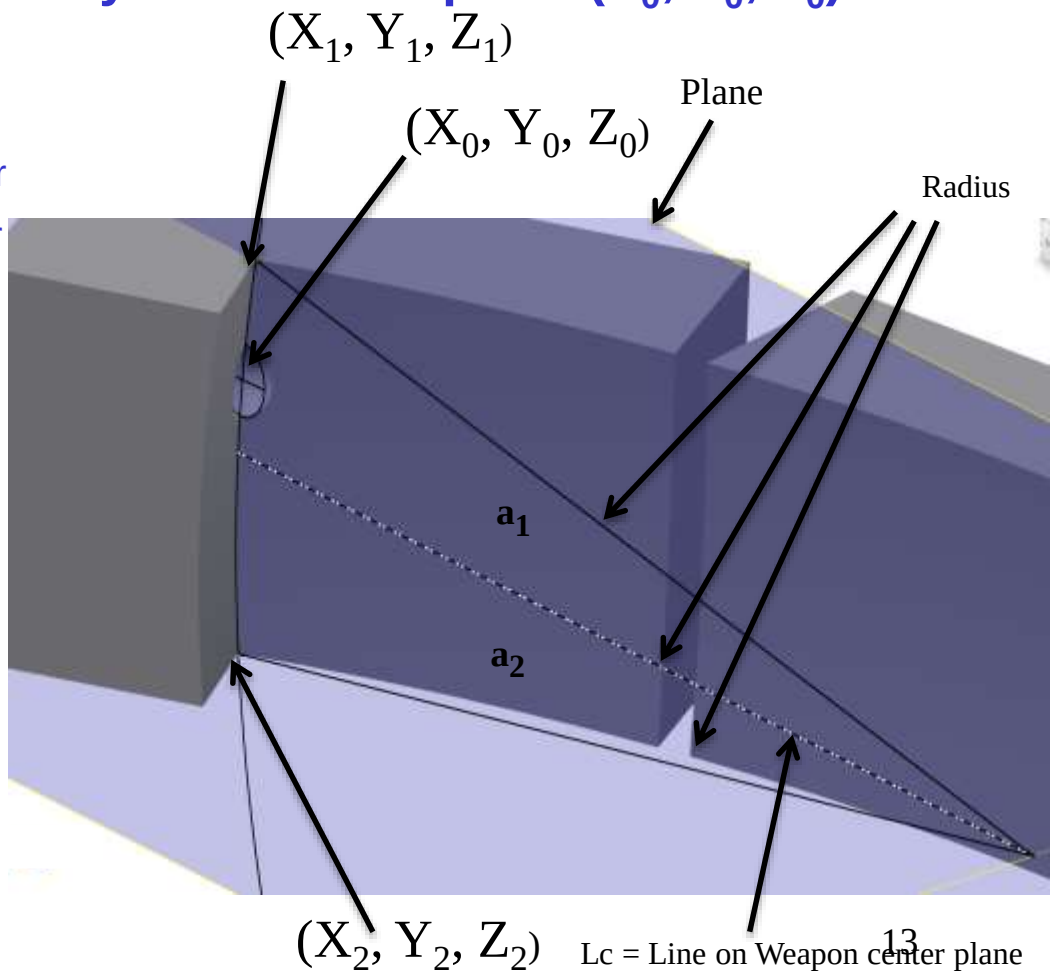
Definition of Terms



Azimuthal Multipliers

Simple Arena Geometries

- **Find angles a_1 and a_2 as defined by hit location point (X_0, Y_0, Z_0) and bundle placement**
  - Radius = $(X_0^2+Z_0^2)^{1/2}$
  - Z_1 = bundle height above weapon center
  - Z_2 = bundle height below weapon center
  - a_1 = angle between (X_1, Z_1) and L_c
  - a_2 = angle between (X_1, Z_1) and L_c
  - $X_1 = (\text{Radius}^2 - Z_1^2)^{1/2}$
  - $X_2 = (\text{Radius}^2 - Z_2^2)^{1/2}$
  - $a_1 = \arctan(Z_1/X_1)$
  - $a_2 = \arctan(Z_2/X_2)$
- **Azimuthal multiplier**
  - $Z_i = 360/(a_1+a_2)$
  - Extrapolate every fragment



Azimuthal Multipliers

Simple Arena Geometries

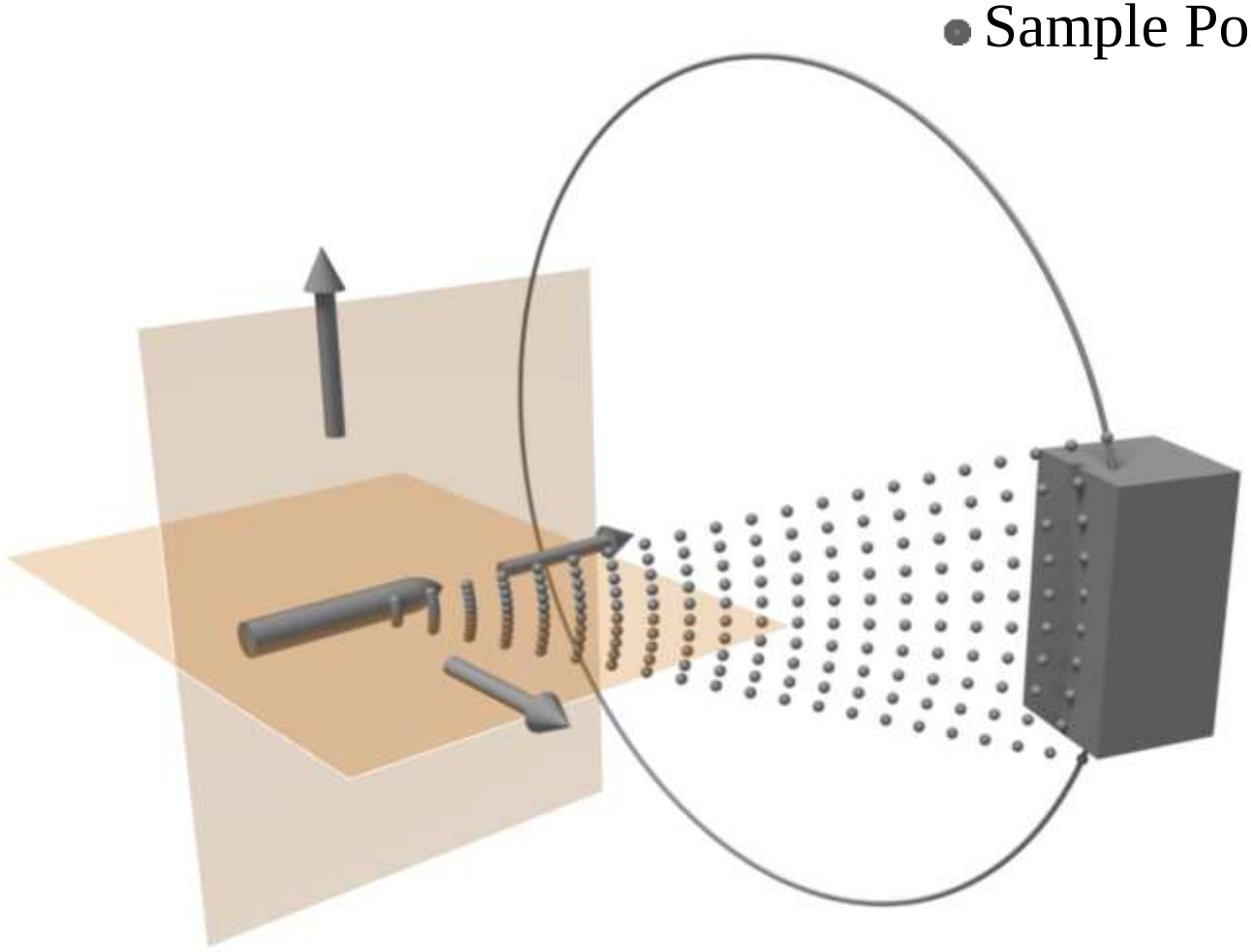
- **Assumptions**
  - The inside surface of the recovery bundles is a smooth cylinder.
  - Fragments that impact the bundle face are collected.
  - The entire azimuthal angle between the top and bottom of the collection bundle is sampled and is the only angle within the polar circle that is sampled.
    - Fragments escape through the cracks in the bundles
    - Bundles beyond 0- and 180-degrees must be adjusted
  - All fragments emanate from the center of the warhead, which is also the center of the polar sphere.
  - Fragmentation is uniformly distributed about the longitudinal axis of the warhead of any given polar zone.
  - All fragment trajectories are straight lines.

- **Eliminate assumptions to improve accuracy, decrease uncertainty, and optimize arena designs**

Azimuthal Multipliers

Arbitrary Arena Geometries

- **Computer code for sampling points for inclusion in a bundle**



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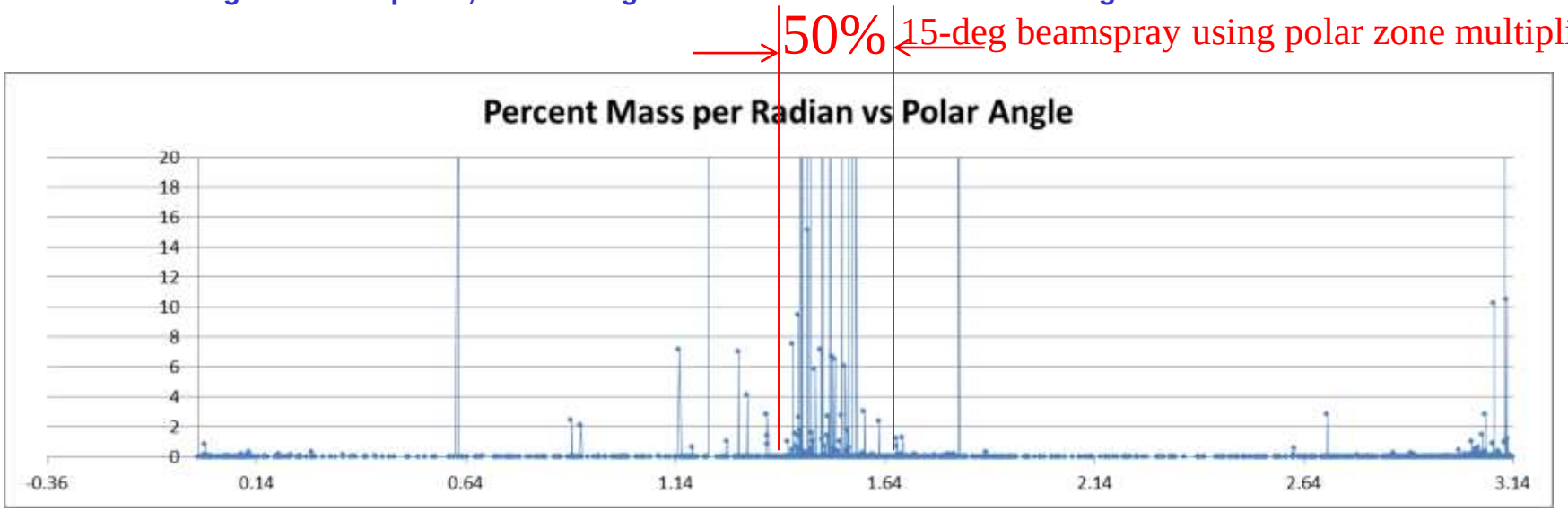
Azimuthal Multipliers

1500 lb Penetrator Analysis

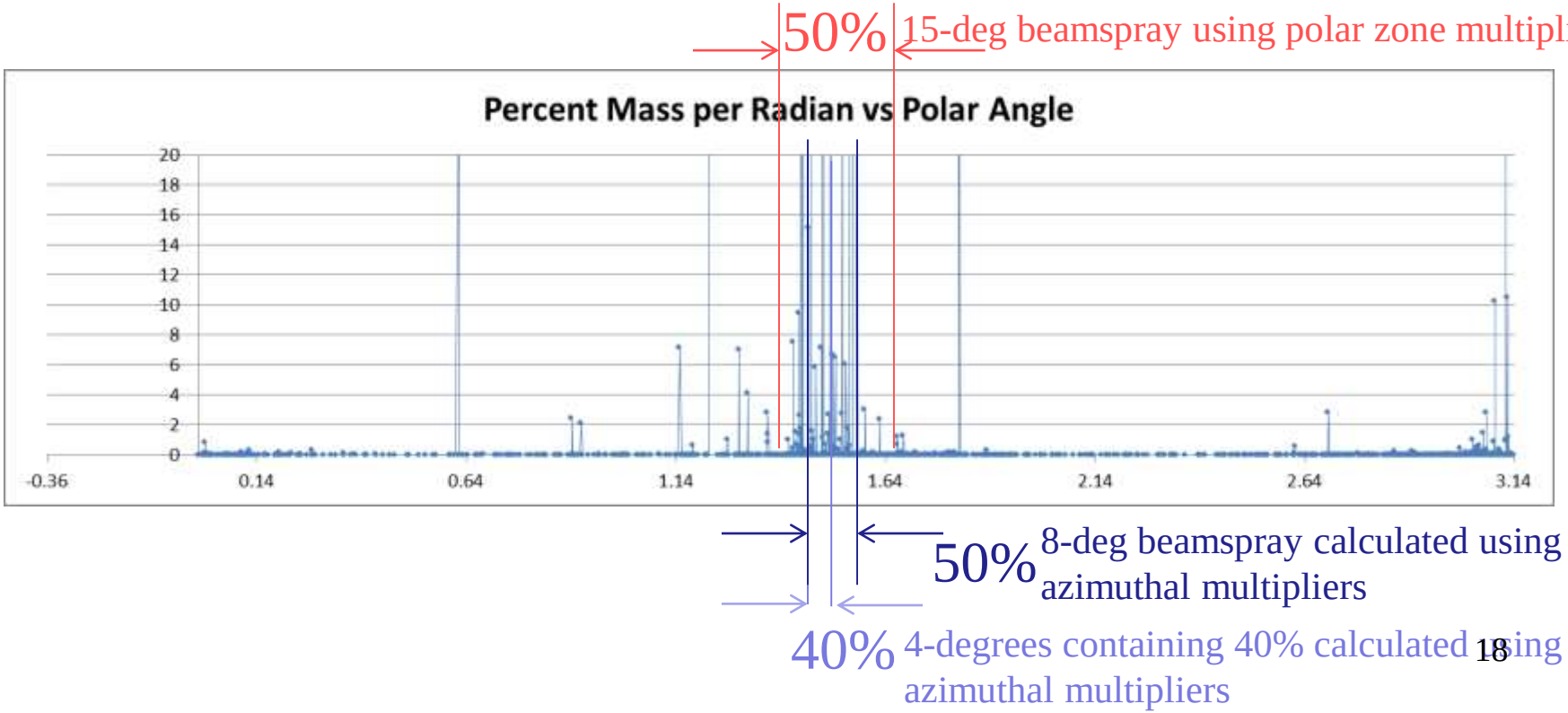
- 1500 lb Penetrator
- Beamspray – the continguous polar zones that contain 50% of the case by mass.
- Precision Doubled - Beamspray reduced by half
  - Using zone multipliers, 50% of fragments were between 80 and 95 degrees



Azimuthal Multipliers

1500 lb Penetrator Analysis

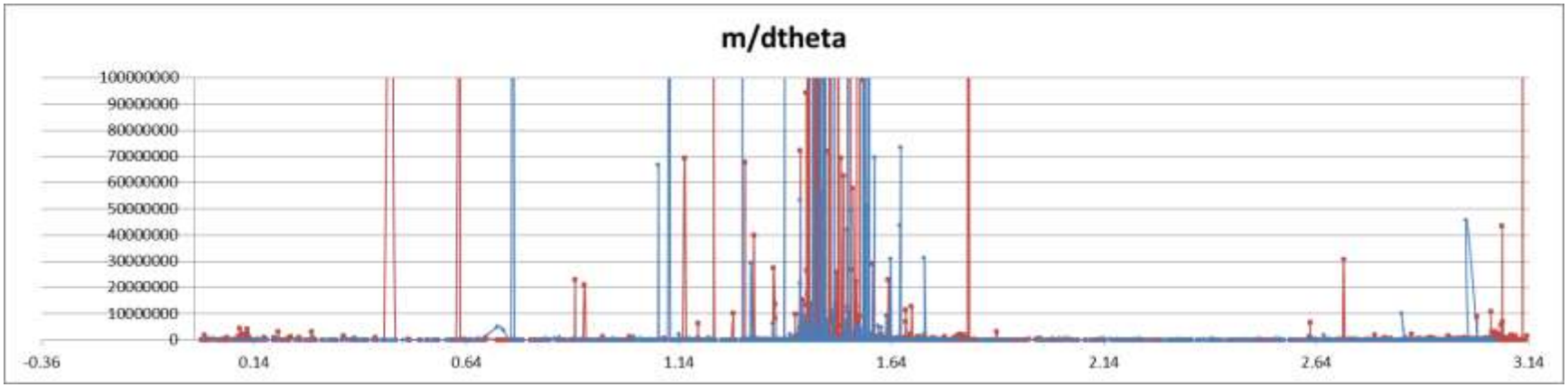
- **Precision Doubled - Beamspray reduced by half** Using zone multipliers, 50% of fragments were between 80 and 95 degrees
  - Using azimuthal multipliers, 50% of fragments were between 82 and 90 degrees
- 40% of fragments are between 82.5 and 86.5 degrees
- 25% of fragments are within approximately 1 degree



Azimuthal Multipliers

1500 lb Penetrator Analysis

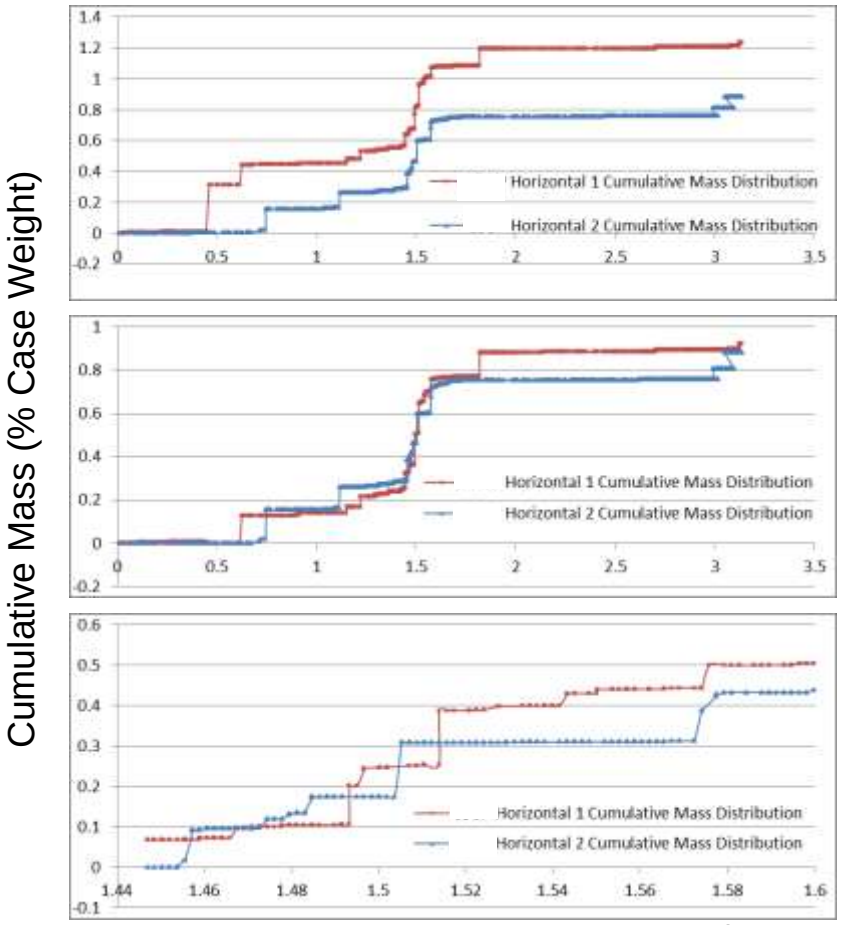
- **Second Horizontal**
- **Similar Results**



Azimuthal Multipliers

Cumulative Mass Distribution

- **Cumulative Distribution of the Percent Mass as a Function of Polar Angle**
  - **Complete 0-180º Fragment Distribution**
  - **0-180º Fragment Distribution Minus Fragment 101 in Horizontal Test 1**
  - **Beamspray Fragment Distribution**
    - **Comparison with Vertical Distributions**
- **Round-to-Round Comparisons**
  - **Kolmogorov-Smirnov Test Statistic**
  - **True Distribution Function with Confidence Bands**
- **Weapon-to-Weapon Comparisons**
- **Similar Fragment Energy Distributions as a Percentage of Gurney Energy Predictions**



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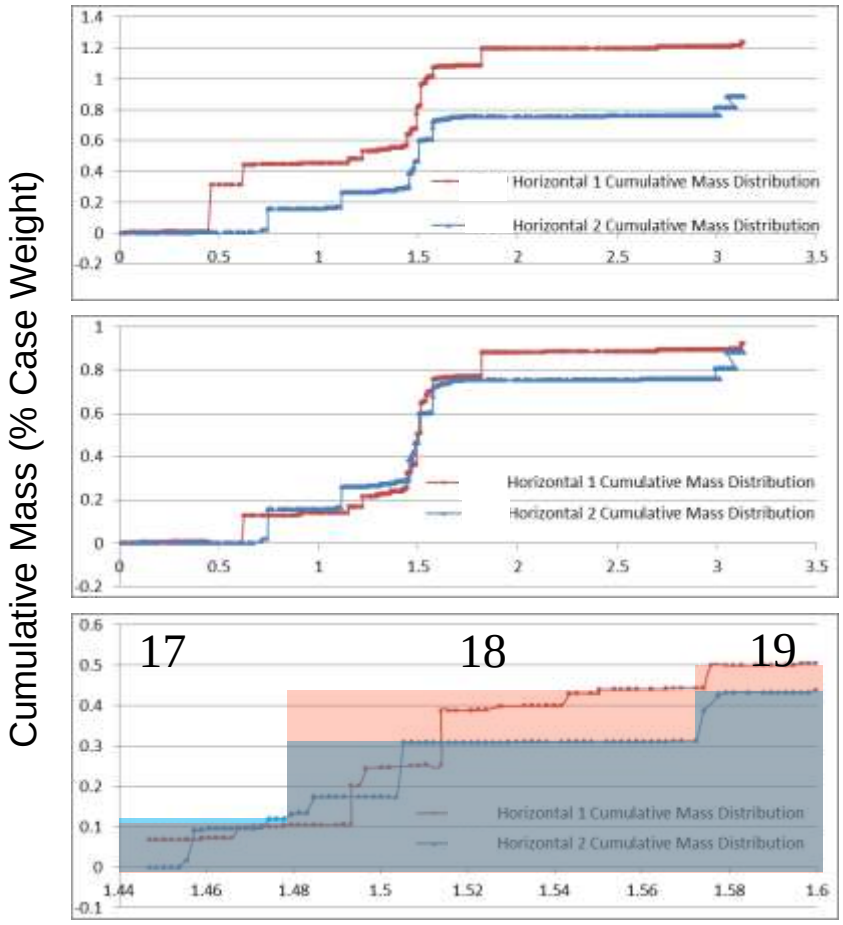

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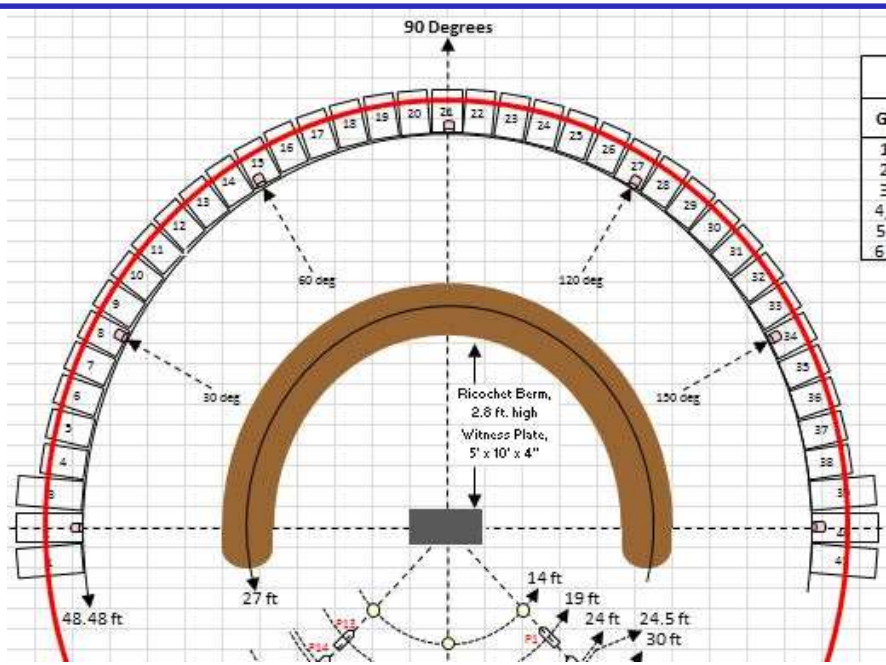
Error/Uncertainty Approximations

- **Fragments escape the cracks in the bundles**

$$e = \frac{(R+d)\pi - R\pi}{R\pi} = d/R$$

  - **Average for 1500 lb penetrator e = 2.1%**
  - **Max for 1500 lb penetrator e = 12.5%**
- **Fragments escape the top of the bundles**

$$e = \frac{\frac{(R+d)h_b}{R} - h_b}{h_b} = d/R$$



- **Higher energy fragments are more likely to escape the bundles**
  - **Collateral Damage**
  - **Safe Escape**
- **Artificially skewing data to the nose and tail**
- **Fragment polar position within the zone**

$$u_\phi = +/-5$$

Azimuthal Multipliers

Error/Uncertainty Analysis

- **Greater Accuracy and Precision**
  - Eliminate inaccuracies and uncertainties from several sources
    - **Essential for more directional weapons under development**
  - Numerical instead of categorical results are better for statistical analysis
    - **Round to round variations**
    - **Weapon to weapon comparisons**

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  - Improved lethality, collateral damage, and safe escape calculations
  - Statistical analysis
- **Improved Weaponeering**

Azimuthal Multipliers

Concurrent Improvements

- **Stereographic Video Analysis**
  - **Pairs of high-speed cameras are used in a frame-by-frame software driven analysis**
    - **Triangulate the position of fragments**
    - **Calculate fragment projected area**
    - **Match fragment to a ballistic trajectory**
  - **Not a cylindrical collection area to extrapolate**
  - **Fragment extrapolation will depend on individual fragment properties**
    - **Size**
    - **Rotation**
    - **Velocity**
    - **Polar angle**
- **3D Z-data Files**

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Summary

- One-time software change
- Eliminate several sources of error in past and future weapon fragment characterizations
- Allow for diverse arena designs
- Save time and money through better designs and analysis
- Define high fragment concentrations especially in developmental directional items
- Compare round to round variability with confidence
- Compare weapon to weapon performance with confidence
- Compatible with emerging technologies including stereographic video and 3D z-data files

- Ultimately – ***put the right weapon on the right target.***

Azimuthal Multipliers

Questions?

- **Questions?**