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Benefits of Steeper Angle of Fall for Precision Projectiles

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Background and Study Objective

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Background

- Battlefield has changed since initial requirements for precision projectiles were developed:
  - Counterinsurgency vs. Mobile Armored Warfare
  - Combat among the population vs. on unoccupied terrain
  - Collateral Damage relationship to strategic outcome
- FA is again relevant: cannon-delivered precision fires have been achieved, demonstrated in combat, and early expectations surpassed
- Requirements have not yet reflected technology capability for AOF.

Study Objective

- Quantify benefits of having steeper Angle of Fall (AOF) for precision projectiles within urban terrain
- Measure of Merits include Engageable Area, Lethality, Operational Effectiveness, and Cost

Effects of Angle of Fall on Engageability of Different Urban Terrains

Methodology: Measuring Effects of Angle of Fall

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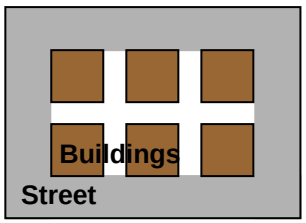
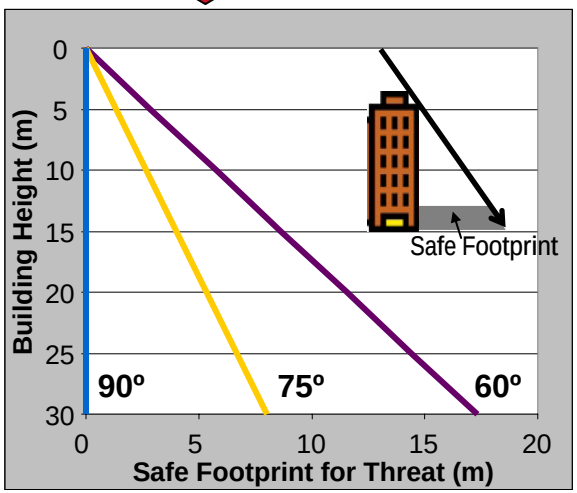
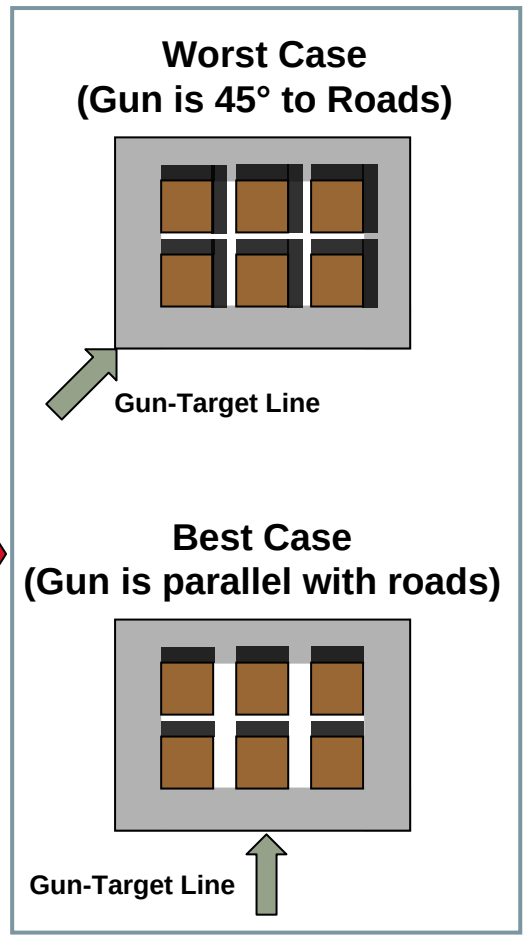
1. Build urban terrain based on real-world measurements of street width, building height, and block sizes



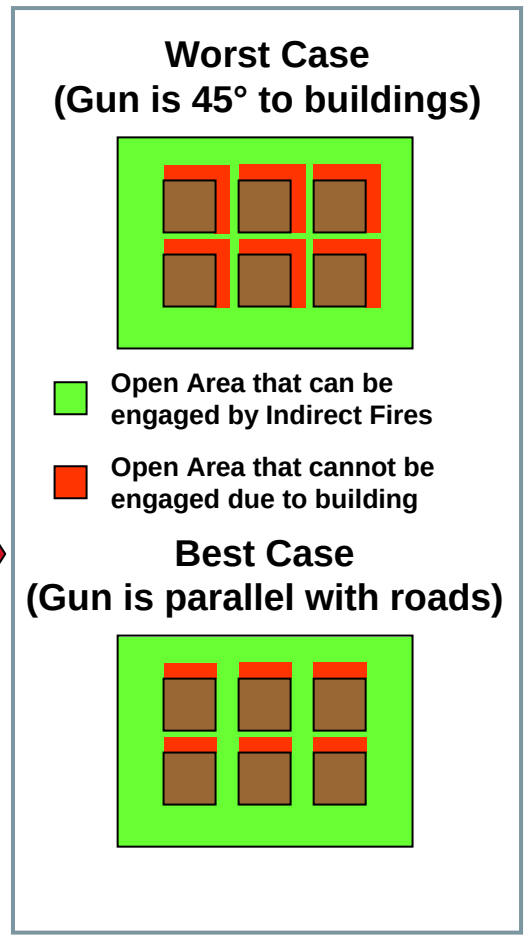


2. Calculate Safe Footprint shadow created by each building for AoF

3. Apply Safe Footprints Shadows to urban terrain for two gun-target lines



4. Measure how much of open terrain is still engageable



Urban Terrain Types

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City Core

- **Block Size:** 340 x 430 meters
- **# Roads:** 2 (vert.) 3 (horiz)
- **Avg. Road Size:** 18.5 meters
- **Avg. Building Size:** 20 x 20 meters
- **Avg. Building Height:** 12.2 meters
- **Height Std Dev:** 6.1 meters
- **Avg. Distance Between Buildings** 8 meters

Commercial

- **Block Size:** 80 x 330 meters
- **# Roads:** 2 (vert.) 4 (horiz)
- **Avg. Road Size:** 18.5 meters
- **Avg. Building Size:** 15 x 15 meters
- **Avg. Building Height:** 6.1 meters
- **Height Std Dev:** 3.05 meters
- **Avg. Distance Between Buildings** 7 meters

Core Periphery

- **Block Size:** 320 x 260 meters
- **# Roads:** 3 (vert.) 4 (horiz)
- **Avg. Road Size:** 16 meters
- **Avg. Building Size:** 18 x 18 meters
- **Avg. Building Height:** 7.6 meters
- **Height Std Dev:** 1.525 meters
- **Avg. Distance Between Buildings** 7 meters

Residential

- **Block Size:** 270 x 330 meters
- **# Roads:** 3 (vert.) 7 (horiz)
- **Avg. Road Size:** 10 meters
- **Avg. Building Size:** 10 x 10 meters
- **Avg. Building Height:** 4.5 meters
- **Height Std Dev:** 1.525 meters
- **Avg. Distance Between Buildings** 5 meters

Industrial

- **Block Size:** 610 x 610 meters
- **# Roads:** 3 (vert.) 3 (horiz)
- **Avg. Road Size:** 18.5 meters
- **Avg. Building Size:** 25 x 25 meters
- **Avg. Building Height:** 9.2 meters
- **Height Std Dev:** 6.1 meters
- **Avg. Distance Between Buildings** 10 meters

1. Building size/height, road size, and distance between buildings from Marine Corps Warfighting Pub (MCWP) 3-35.3 – Military Operations in Urban Terrain

2. Block size and number of roads obtained from observations of Baghdad terrain using Google Earth.

Analysis:
Effects of Angle of Fall on Engageability

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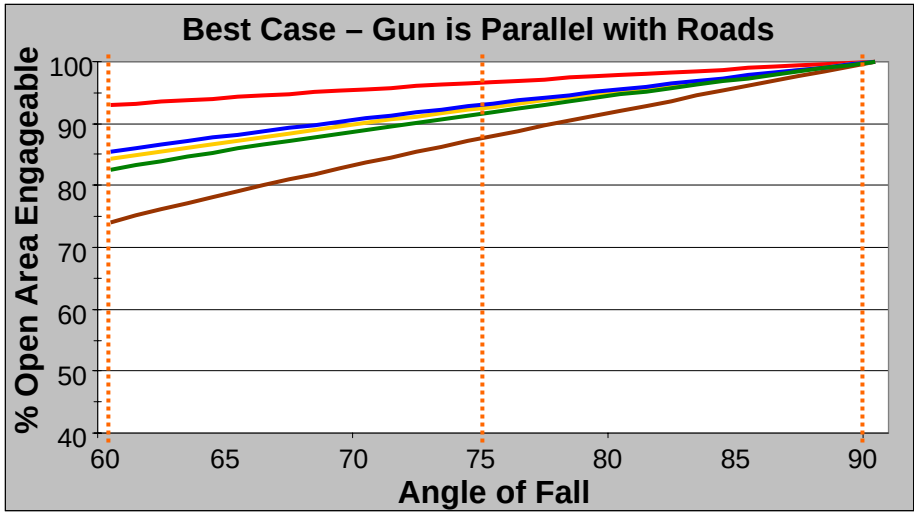

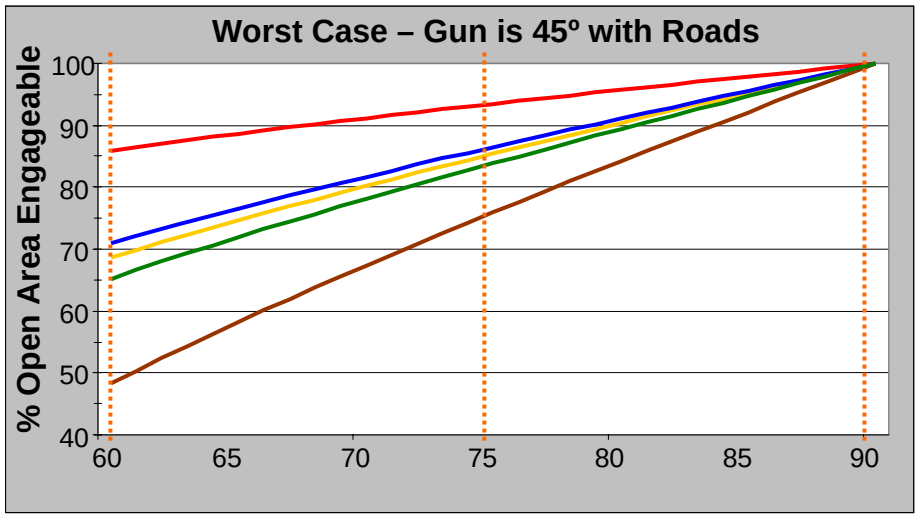

Urban Terrain Type

- City Core
- Commercial Ribbon
- Core Periphery
- Residential Sprawl
- Outlying Industrial Areas

- **MoE:** Measure what percentage of the open area is engageable by indirect fire
  - Open Area is any area not occupied by a building
  - Indirect Fire cannot engage open area if round's angle of fall would clip the nearby building
- **Results:**
  - Steeper AoF can engage more open area in all urban terrain types:
  - % more open area engageable in worst case vs. 60º
    - City Core: **75º:** +57.5% **90º:** +107.3%
    - Commercial: **75º:** +8.8% **90º:** +16.3%
    - Core Periph: **75º:** +24.5% **90º:** +45.8%
    - Residential: **75º:** +21.9% **90º:** +40.9%
    - Industrial: **75º:** +28.5% **90º:** +53.2%

Steeper Angle of Fall enables Indirect Fire to engage significantly more Urban Terrain, especially if ideal Gun Placement is not possible

Methodology:
Measuring Effects of Angle of Fall in a Real City

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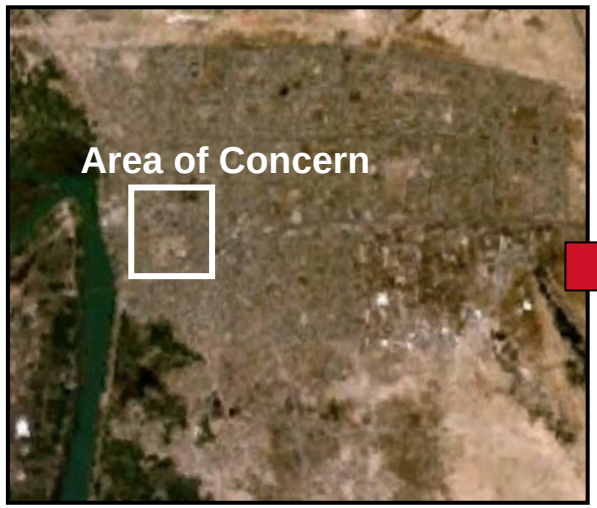
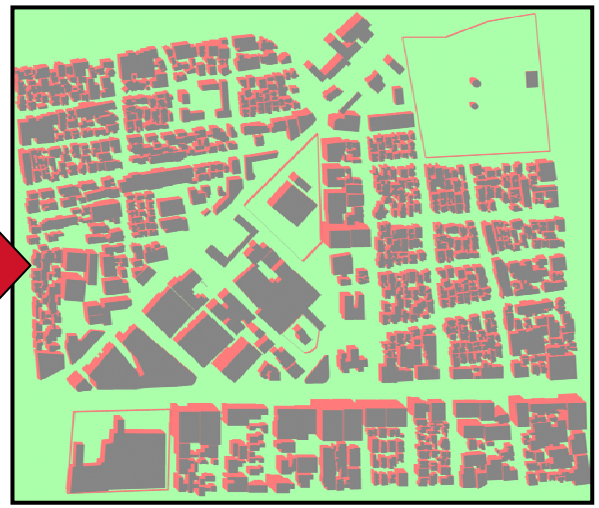
Analysis Questions: Does a steeper Angle of Fall (AoF) provide a tactical advantage in an urban area? How much area is "hidden" by buildings?





1. **Use a real-life example of terrain with varying urban areas (Al Fallujah):**
   - **Residential Sprawl**
     Many small buildings, close together
   - **City Core (downtown)**
     Large / tall buildings
   - **Commercial District**
     Large buildings / warehouses

   See middle picture for examples

2. **Convert terrain into a 3d model.**
   - Building size based on satellite images
   - Building height based on shadow analysis of satellite images and from aggregate data collected from various urban areas

3. **Use sophisticated graphics programs to cast light down on model at desired AoF.**
4. **Measure the amount of area still engageable**
   - Non-Engageable "Safe Footprint" Shadows in red
   - Engageable area in green

Analysis:
Effects of Angle of Fall on Engageability

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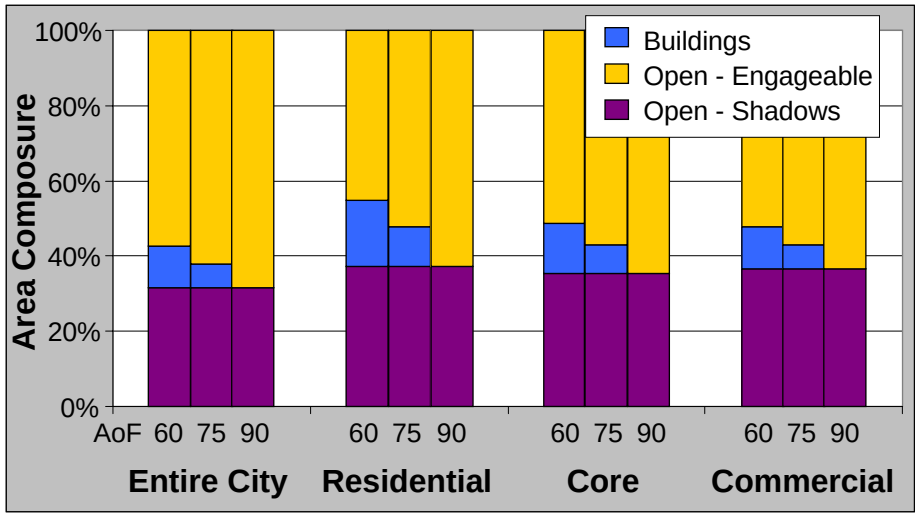

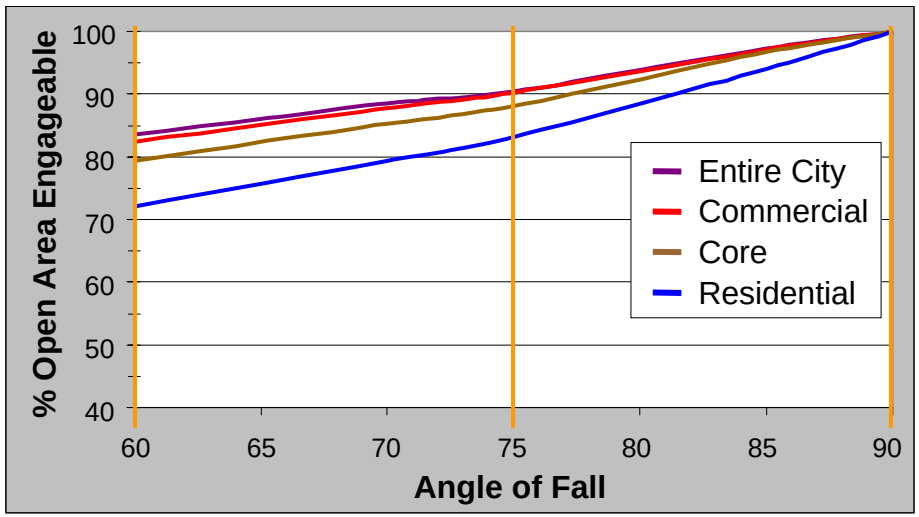

- **MoE:** Measure what percentage of the open area is engageable by indirect fire
  - Open Area is any area not occupied by a building
  - Indirect Fire cannot engage the open area if the round's angle of fall would clip the nearby building
  - Area Composure:
    - ***Residential:*** *37% Buildings* *63% Open*
    - ***City Core:*** *35% Buildings* *65% Open*
    - ***Commercial:*** *37% Buildings* *63% Open*
    - ***Entire City:*** *31% Buildings* *69% Open*
- **Results:**
  - Steeper angles of fall can consistently engage more open area in all Al Fallujah terrain types
  - % more open area engageable vs. 60º
    - Residential: **75º:** +15.2% **90º:** +38.6%
    - City Core: **75º:** +10.9% **90º:** +25.9%
    - Commercial: **75º:** +9.4% **90º:** +21.3%
    - Entire City: **75º:** +8.4% **90º:** +19.7%

In central Al Fallujah, a round with a steep Angle of Fall enables Indirect Fire to engage significantly more of the city's open area

Effects of Angle of Fall on Lethality, Operational Effectiveness, and Cost

Analysis:
Effects of Angle of Fall on Lethality

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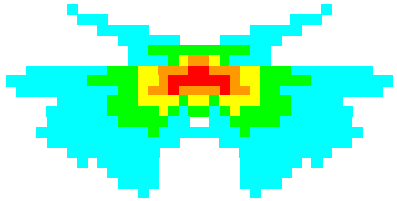
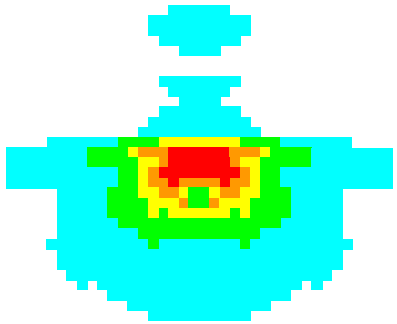
Example
Pk Map



AOF = 60º

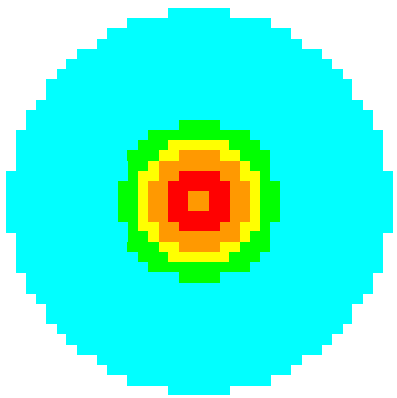
P_K

1.0-0.8
0.8-0.6
0.6-0.4
0.4-0.2
0.2-0.05



AOF = 75º

Gun-Target
Line



AOF = 90º

Comparison of Lethality vs. 60º AoF

AoF	75º	90º
Total Area	+61%	+206%
Lethal Area	+62%	+141%
Pk > .8	+120%	+180%
.8 > Pk > .6	+33%	+189%
.6 > Pk > .4	+58%	+67%
.4 > Pk > .2	+39%	+21%
.2 > Pk > .05	+67%	+272%

Total Area = Area affected by munition

Lethal Area = Measure of effectiveness for particular target/weapon pairing. Computed as the sum of (Pk*Area) across all individual cells in the PkMap.

Increased Angle of Fall results in significantly Increased Lethality

Methodology:
Measuring effects of AoF on Operational Effectiveness

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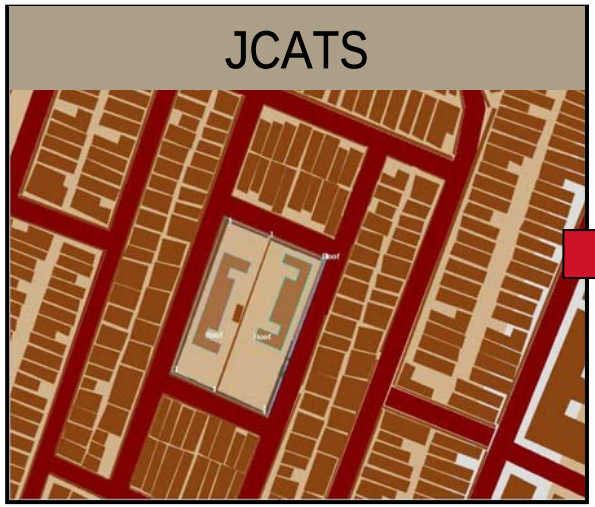
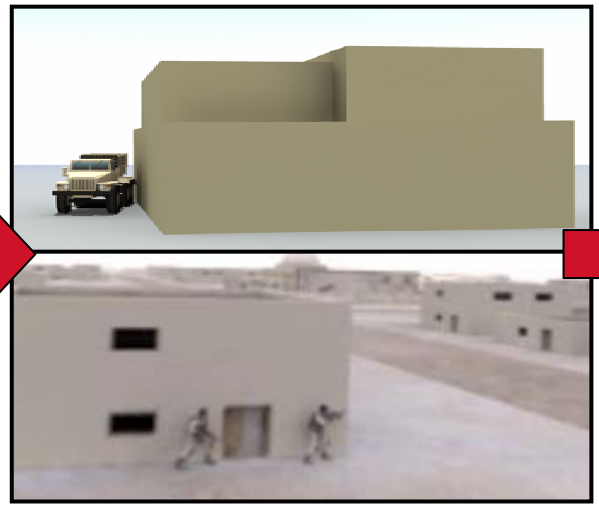
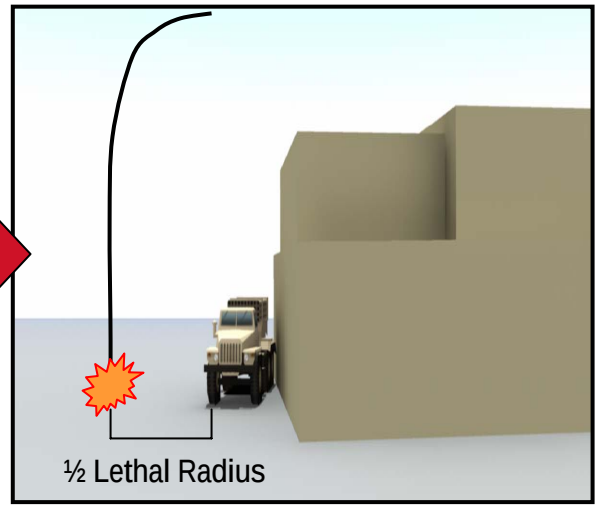
Analysis Questions: In urban terrain, what Angle of Fall (AoF) is necessary to put effects on target and to minimize structural collateral damage?







1. **Build the 5 urban terrain templates into JCATS :**
   - City Core (downtown)
   - Commercial District
   - Core Periphery
   - Residential Area
   - Industrial Area
- **Results based on average across all terrains**

2. **Place primary targets behind buildings in the different terrains.**
   - Targets placed in alleys 0.5 – 1.5m away from building
   - Represents truck "parked" next to building and infantry hugging building wall
   - Assume reporting TLE is 10m

3. **Launch rounds at the targets with varying CEP and AoF. Measure rounds to reach 30% EFD and measure collateral damage.**
   - Aimpoints offset from target = ½ lethal radius (or middle of Alley if lethal radius too large)
   - Lessens chance of impacting nearby buildings
   - Clipping buildings played

Analysis:
Effects of Angle of Fall on Operational Effectiveness

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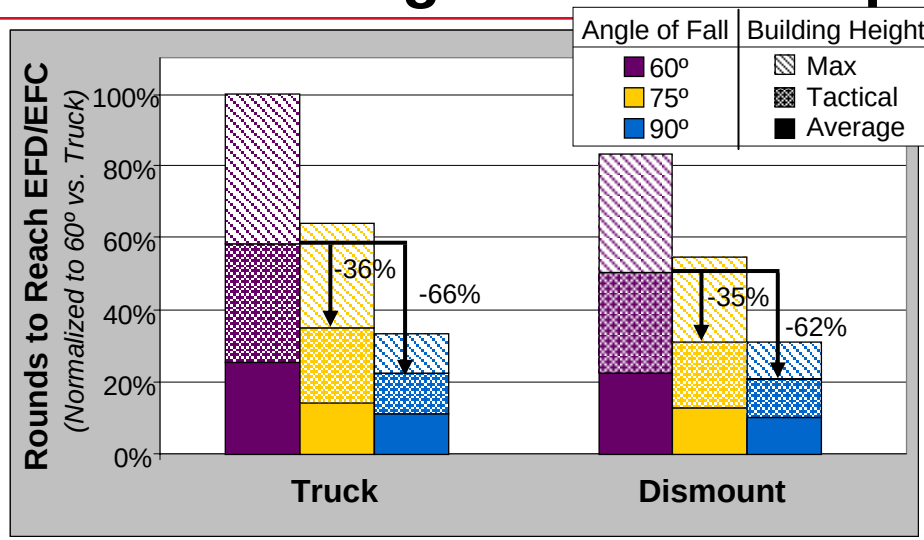

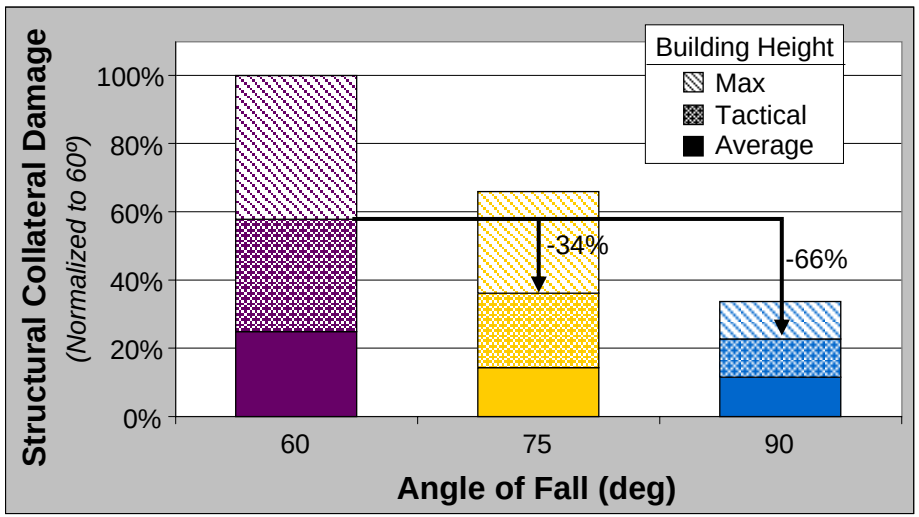

- **Building Heights:**
  - **Average building height** comes from the 5 Urban Terrain Templates
  - **Max building height** is average + 3-sigma variance
    - *Sigma values provided in the Urban Terrain templates*
  - **Tactical building height** is between average and max
    - *Threat would realize capability of projectiles to come over buildings*
    - *Threat would tactically choose a taller than average building to mitigate this advantage*
- **MoE:** Rounds needed to reach EFD of 30%; Collateral Damage produced from rounds impacting on/near buildings
  - Assumes 10m TLE
  - Rounds will clip building if AoF is too shallow
- **Results for the Tactical Case:**
  - Comparison to 60º Angle of Fall
    - % fewer rounds vs. Truck: **75º:** -36% **90º:** -66%
    - % fewer rounds vs. Dismnt: **75º:** -35% **90º:** -62%
    - % Less Structural Damage: **75º:** -34% **90º:** -66%

Steeper Angle of Fall provides significant Operational benefits against targets in Urban Terrain; Targets are eliminated with fewer rounds and less Structural Damage is created

Analysis:
Effects of Angle of Fall on Cost

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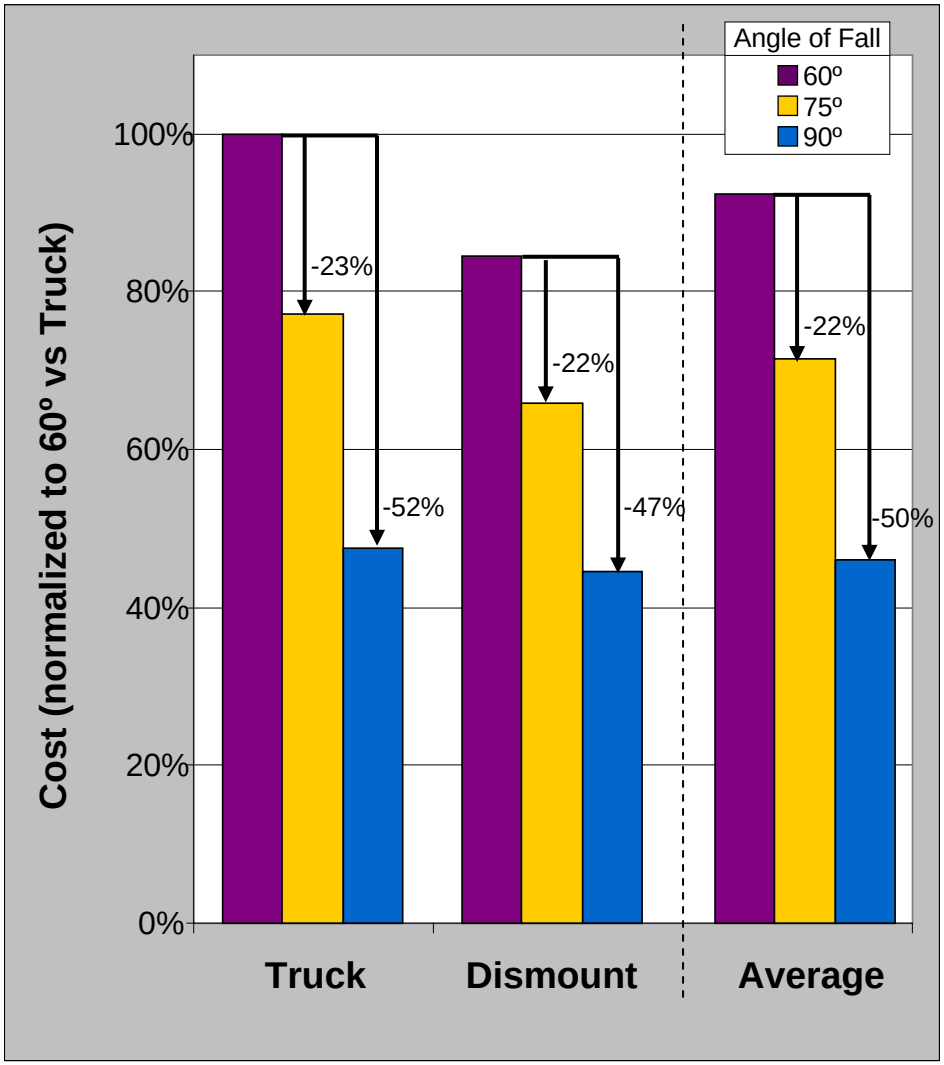

- **Methodology:** Apply costs to the number of rounds required to reach EFD computed by JCATS
- **Assumptions:**
  - Tactical building height results used
  - 75º round costs 20% more than 60º round
  - 90º round costs 40% more than 60º round
- **Results:**
  - Steeper angle of fall results in significantly less cost
    - *Steep angle of fall maximizes lethality*
    - *Steep angle of fall avoids clipping of buildings*
  - If 10 missions are fired on each target daily:
    - *75º will save $363.8k per day*
    - *90º will save $812.7k per day*
  - To be as cost effective as a round with 90º:
    - *A round with 60º would need a unit cost 64% less than the 90º round*
    - *A round with 75º would need a unit cost 45% less than the 90º round*

Steeper Angle of Fall achieves effects for less cost; Cost per Kill much more affordable