Characterization of Composite Spaced Armor Performance

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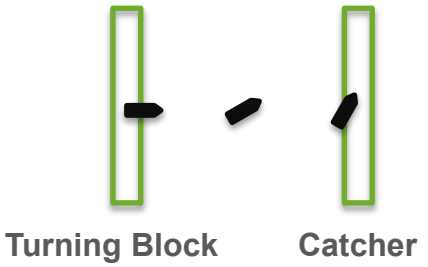
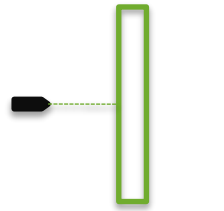
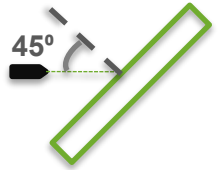
Spaced Armor Background

- **"Turning Block" enables spaced armor to defeat armor-piercing projectiles at low areal density.**
  - Turning Block is a trade name and manufactured by Hardwire LLC [1].
- **Works by imparting an asymmetrical load onto the round, causing it to tumble.**
- **Previous testing has shown performance is fairly consistent at 0º obliquity.**
- **Limited testing had been done at other obliquities.**
  - Due to the anisotropic nature of composite armor, performance at nonzero obliquities is of concern.







[1] Tunis, G. C., S. Kendall, and S. L. Kinnebrew. U.S. Patent 8,739,675 B2, 2014.

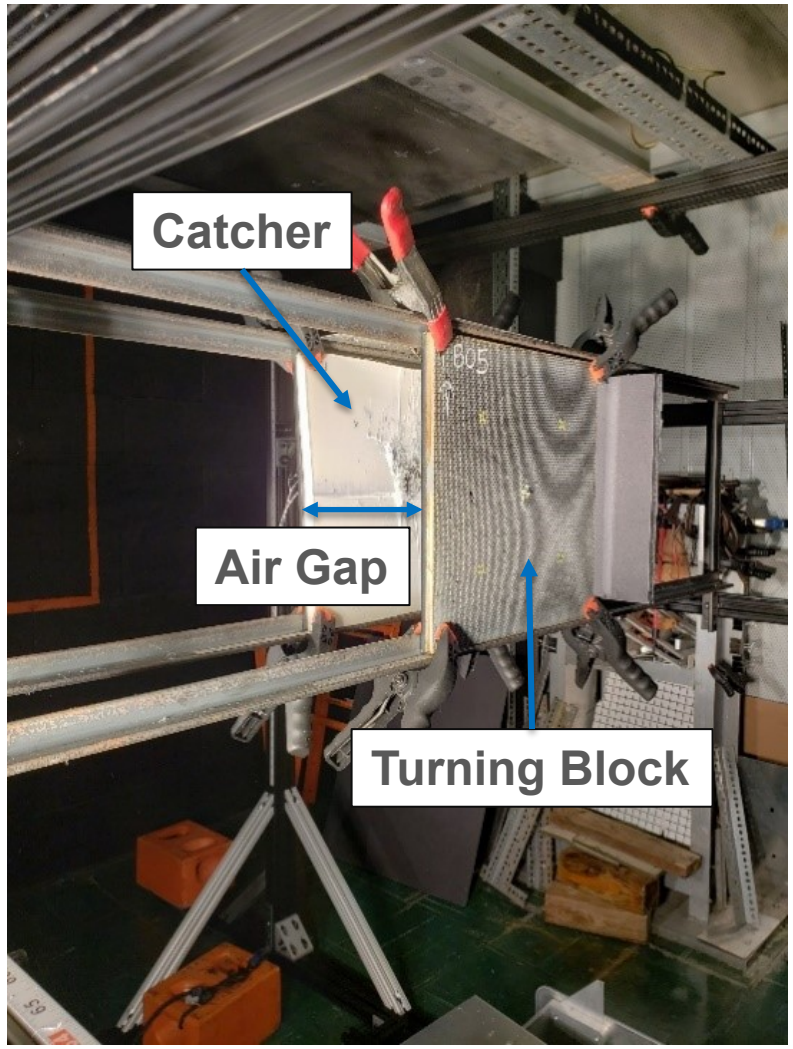
Test Objectives

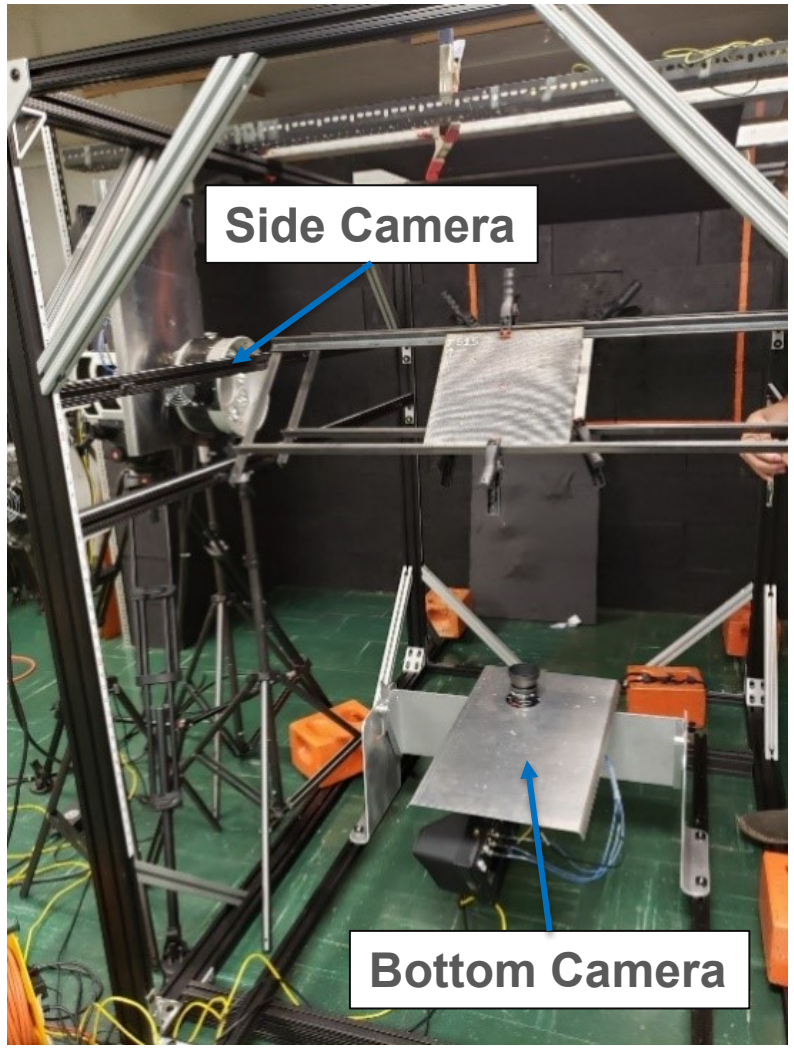
- **Better understand how Turning Block spaced armor performs at various obliquities.**
  - Explore how armor angle affects the turning of the round.
- **Analyze highspeed video and V_{50} data to establish a confidence level for performance of the spaced armor at various obliquities.**
- **Hypothesis: As obliquity varies, the tumble rate of the bullet changes. *It is speculated that there will be a small range of obliquities in which there will be no bullet tumble.***

Withheld Information:

- **The areal density of the armor, the threat being tested, and the velocity of the round are excluded due to their security classifications.**
- **The classified velocity used will be referred to as the "reference velocity."**
  - Each subsequent velocity included will be a delta (Δ), or numerical difference, from this unstated reference velocity.

Test Setup

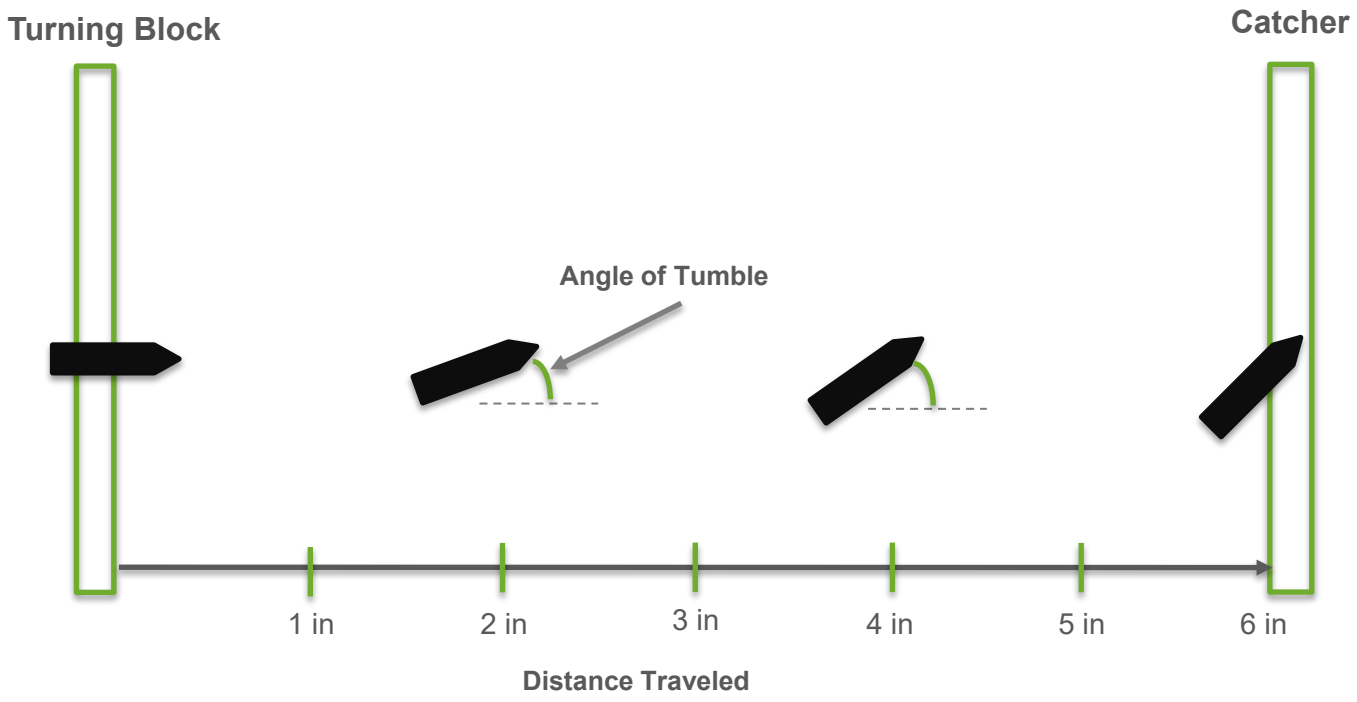




Test Parameters

Testing Conducted:

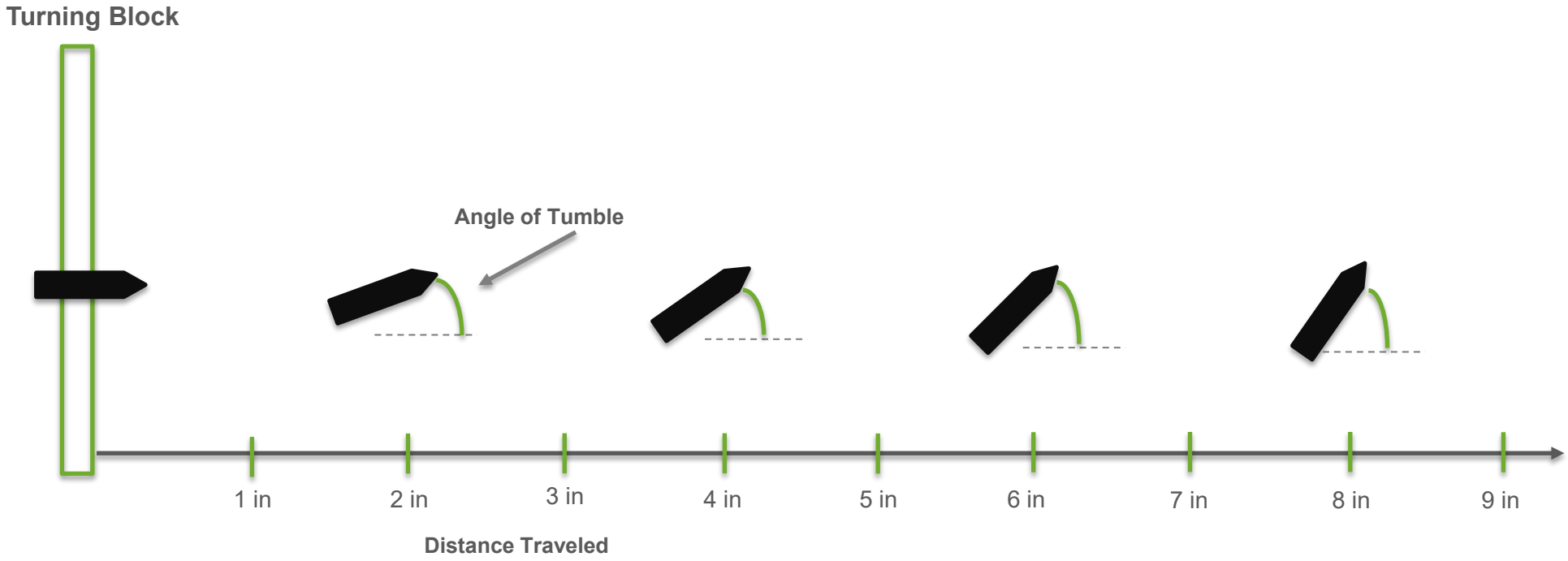
1. **V_{50} Testing**
   - Testing parameters: Turning Block, 6-in air gap, catcher, variable velocity
   - Conducted at multiple obliquities
   - Complete penetration vs. partial penetration guaranteed



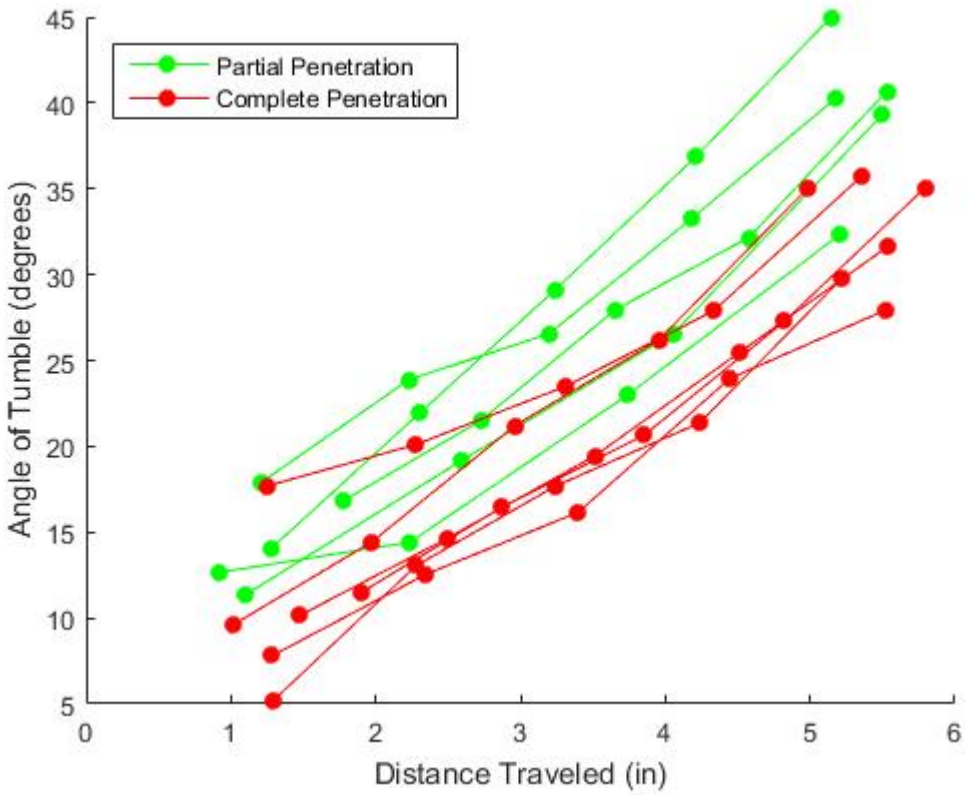
Test Parameters

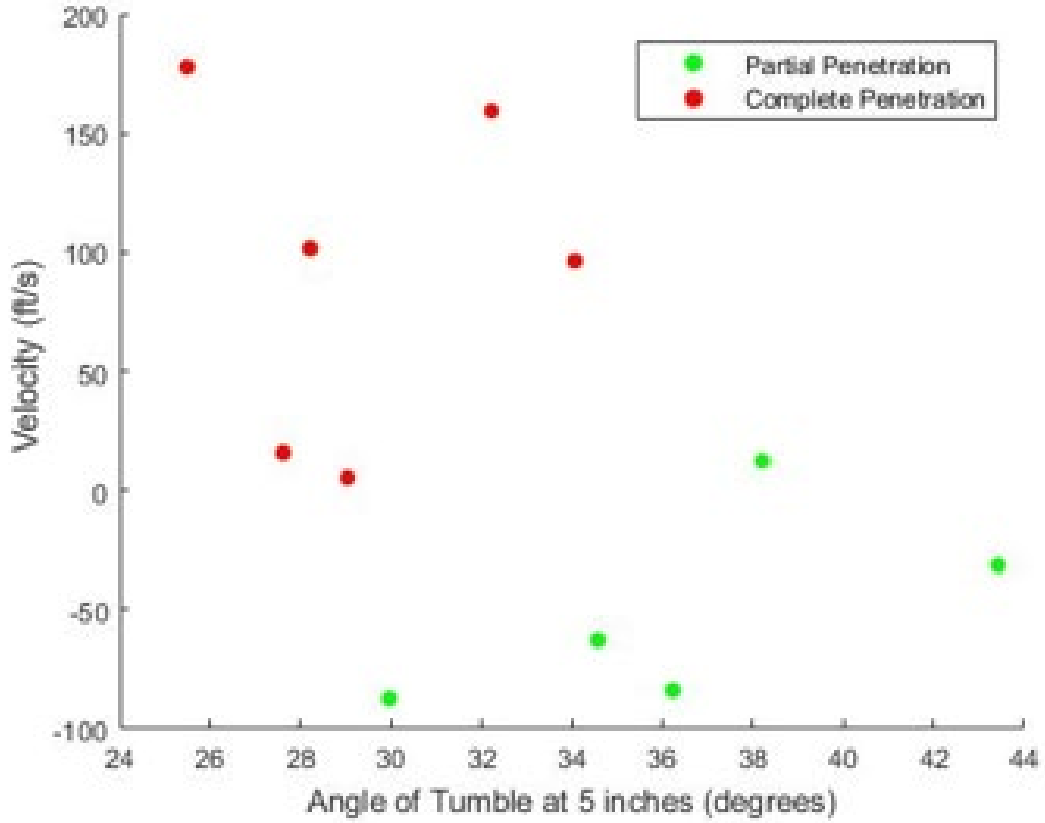
Testing Conducted:

2. **Angle of Tumble vs. Distance Traveled**
   - Testing parameters: Turning Block, limitless air gap (data recorded up to 10 in), no catcher, constant reference velocity
   - Probable partial penetration: ≥ ±40° of tumble; probable complete penetration: < ±30° of tumble



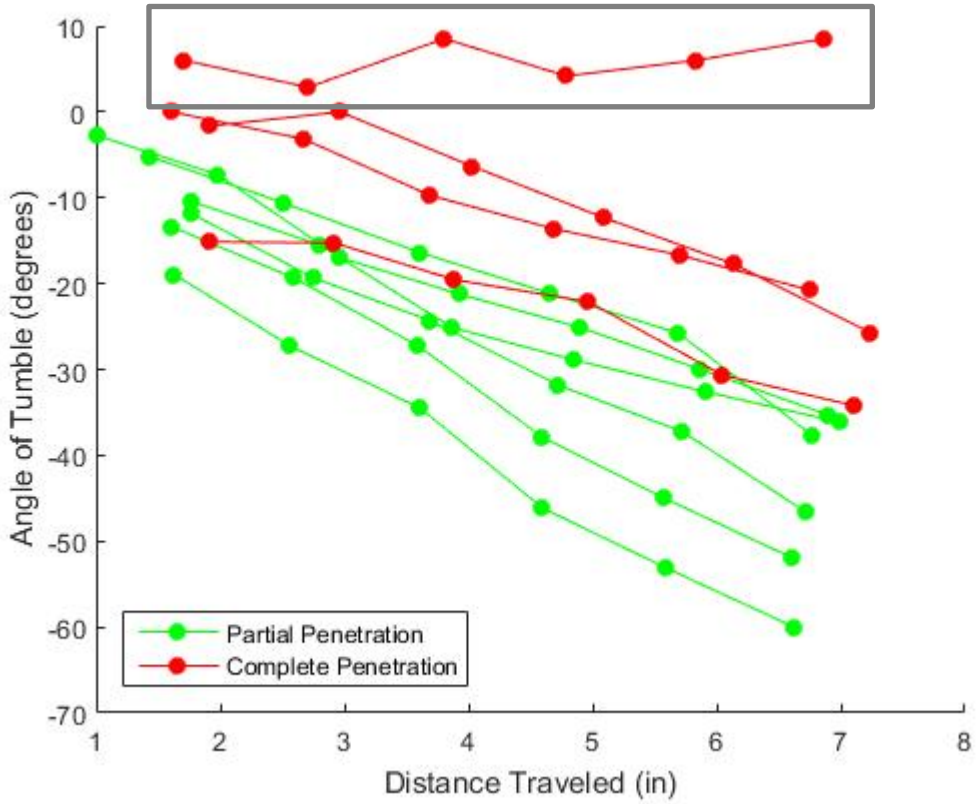
V_{50} Testing at 0º Obliquity

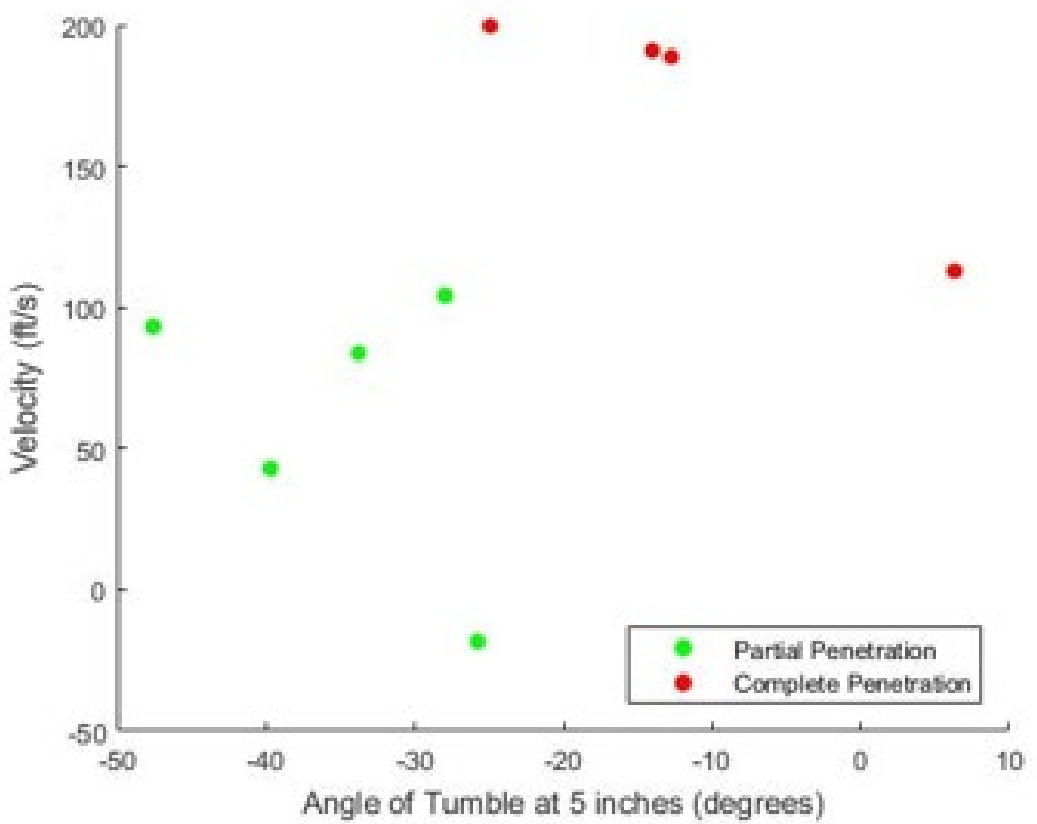




- **V_{50}: ∆5.8 ft/s**
- Mostly linear relationship between angle of tumble and distance traveled—the Turning Block imparts a constant tumble rate on the round.
- As the velocity increases and/or the tumble decreases, it appears that the round becomes more difficult to stop.

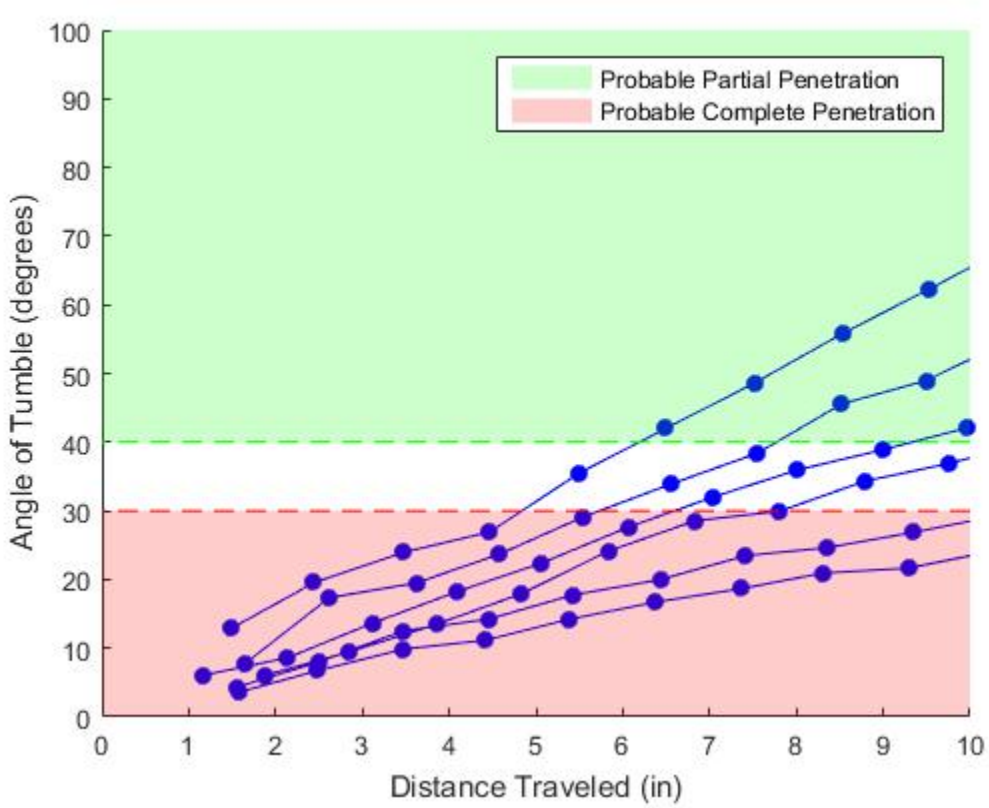
V_{50} Testing at 45º Obliquity



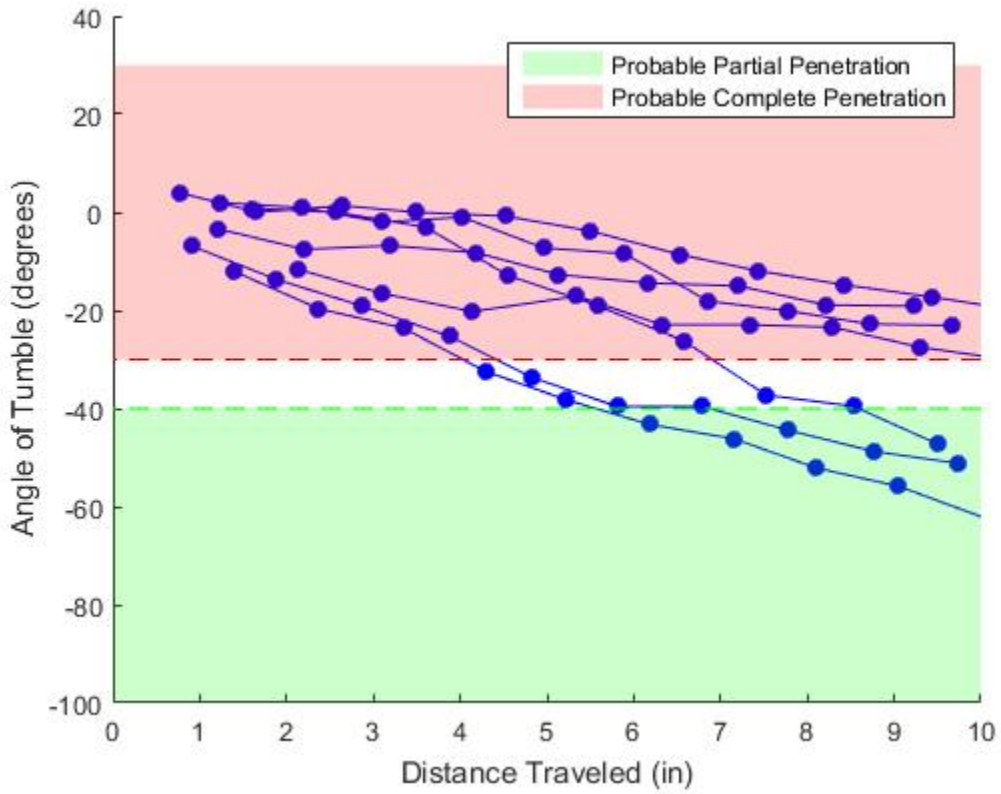


- **V_{50} : ∆147.3 ft/s; improved V_{50} over 0º**
- However, 1/10 shots exhibited almost no tumble, causing it to pass straight through the armor system.

Angle of Tumble vs. Distance Traveled: 0º and 45º



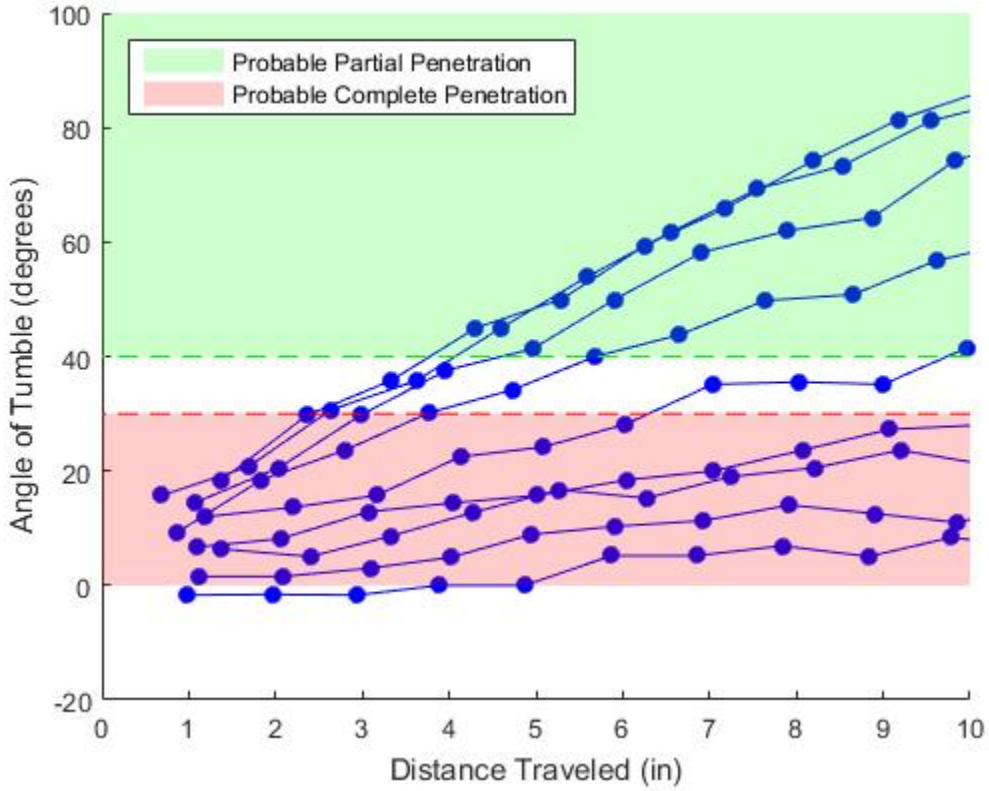
0º Obliquity



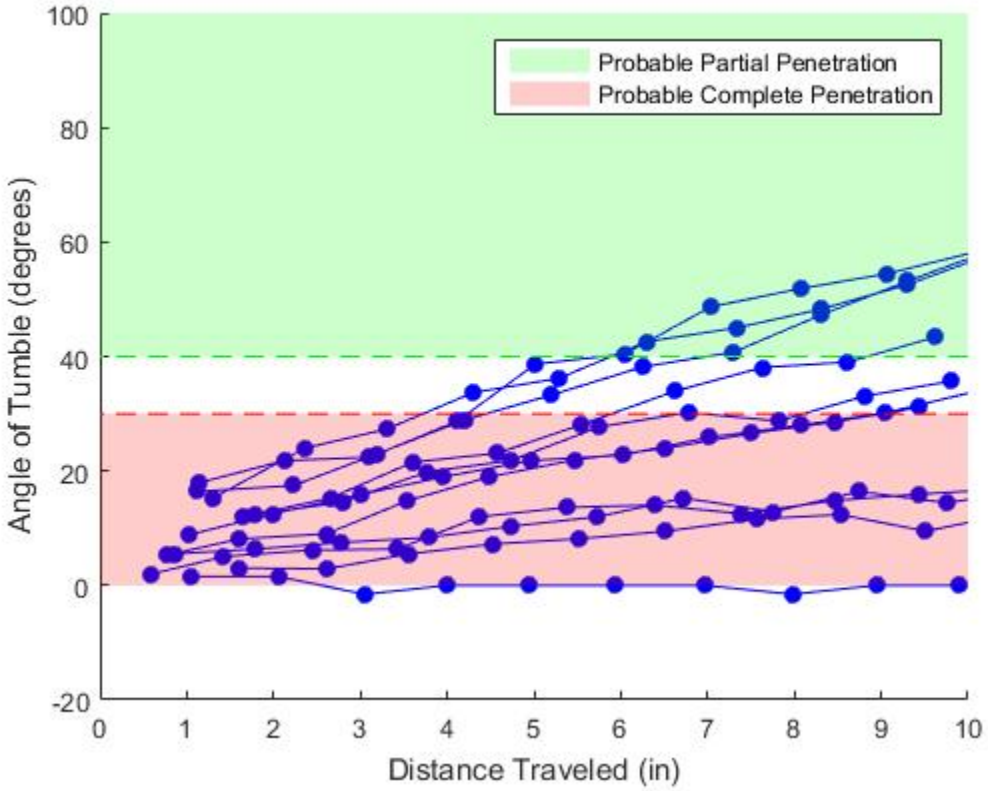
45º Obliquity

- Positive slope at 0° vs. negative slope at 45° indicates opposite directions of tumble rotation.

Angle of Tumble vs. Distance Traveled: 30º and 35º



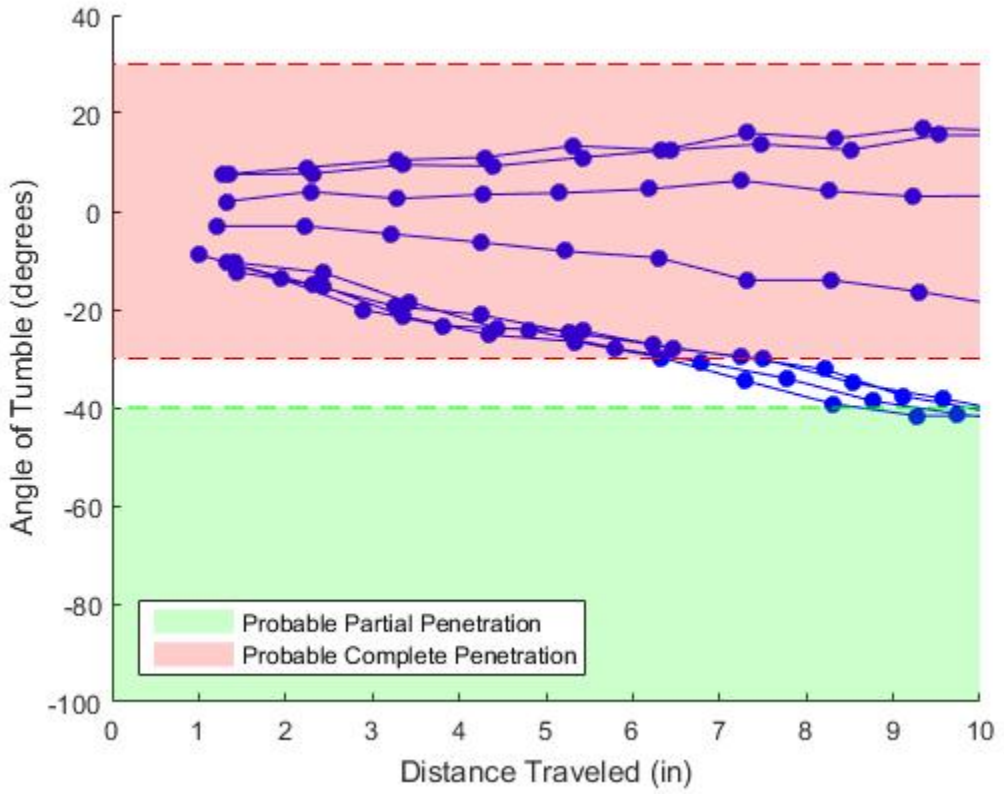
30º Obliquity

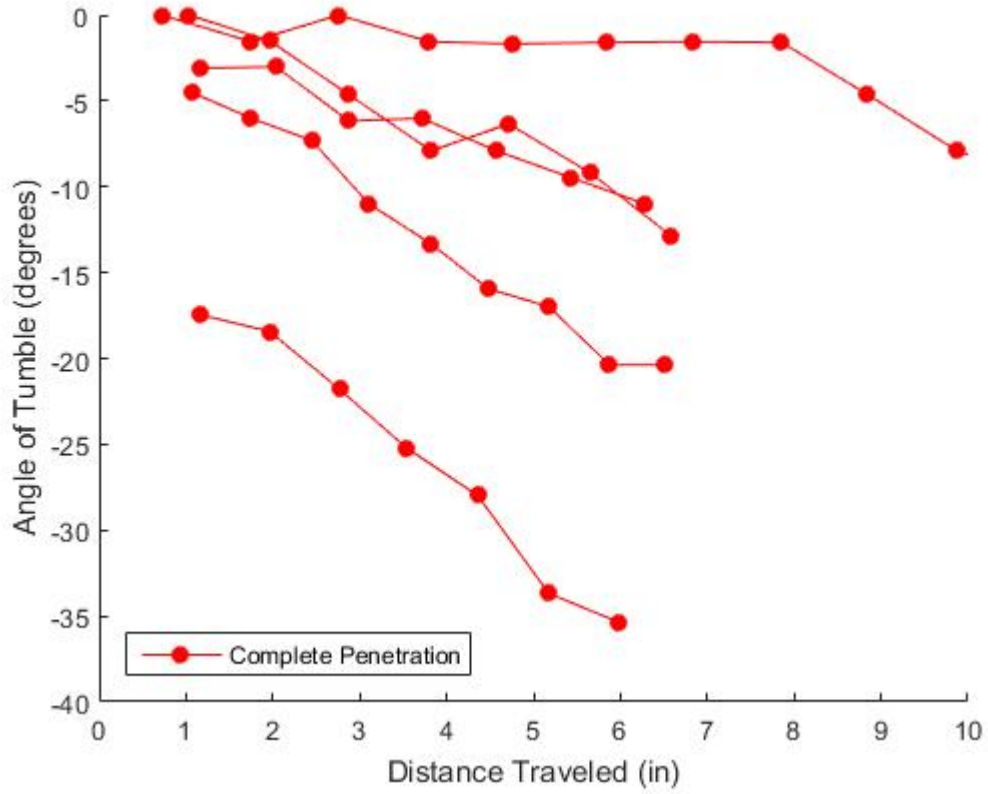


35º Obliquity

- Average rate of tumble decreased and scatter increased compared to 0°.

Angle of Tumble vs. Distance Traveled: 40º; Attempted V_{50} at 40º





40º Obliquity

- Hypothesized "inflection point" is found. Numerous shots exhibit little-to-no tumble.
- V_{50} is attempted at this obliquity; however, only complete penetrations are captured.

Conclusions

- **At normal obliquity, this armor performs as intended.**
  - Effective at stopping the projectile at much lower weights than traditional armor systems.
- **There appears to be an inflection point, at or near 40º, where the tumble of the round is greatly reduced.**
  - Intermittent, degraded performance is present between 30º and 40º.
- **We can no longer assume normal obliquity to be the worst-case-scenario in armor testing, especially with composite armor.**
  - Understanding the mechanism of defeat is necessary to characterize armor performance.

Future Work

- **Test the armor system at additional obliquities.**
  - Comprehensive angle sweep.
- **Repeat testing to determine statistically-significant confidence intervals at each obliquity.**
- **Test spaced armor's capability to stop higher order threats by increasing the areal density of the Turning Block.**
- **Publicize the enhanced capability that this armor system represents.**
  - While the armor system suffers from a small range of vulnerable shot lines, it represents a new, effective, lightweight class of high-performance armor.
- **Improve off-angle performance of the armor system.**