Applying SC3D to Verify Force Protection with Hard Kill Active Protection Systems

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Background

- **Survice conducted trade study to find best option Active Protection System for USMC**
  - TRL ≥ 8
- **Identify selection criteria**
  - Performance, SWaP-C, etc.
- **Quantification Methodologies**
- **SURVIVABILITY, RESIDUAL DAMAGE/OCCUPANT VULNERABILITY from EINJ**
  - Composite Armor
- **NB: Other outcomes are possible in CM SC engagement**

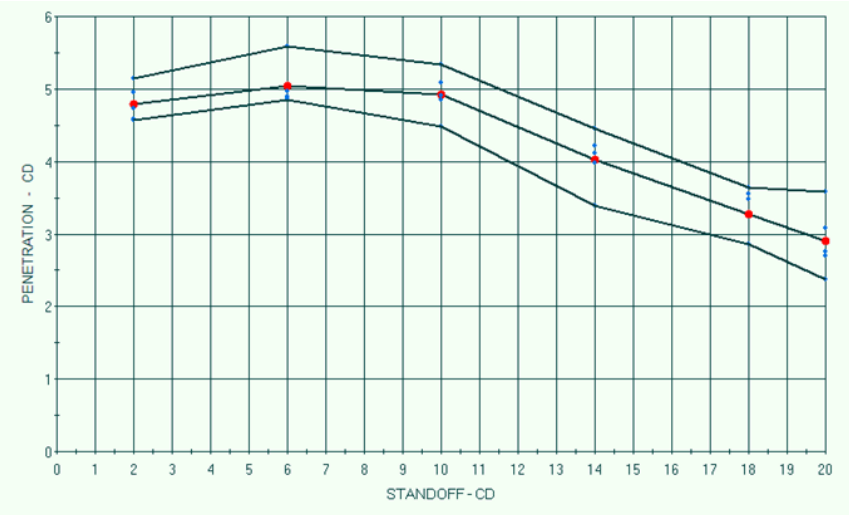
Engagement Outcome Definitions

Jet-Producing Outcomes	Descriptions
Built-In Standoff with Normal Jet (BISONJ)	Warhead initiates normally upon impact on the vehicle with no damage to the warhead.
Early Initiation with Normal Jet (EINJ)	Warhead initiates normally as a result of fragment impacts with no damage to the warhead and produces a normal jet.
Built-In Standoff with Damaged Jet (BISODJ)	Warhead initiates normally upon impact on the vehicle but with damage to the warhead due to fragment hits at intercept, resulting in a damaged jet.
Early Initiation with Damaged Jet (EIDJ)	Warhead initiates normally as a result of fragment impacts, damage is incurred to the warhead due to fragment hits prior to detonation and a damaged jet produced.
Fragment Induced Detonation (FID)	A fragment hit on the warhead causes a detonation. The detonation is initiated off of the axis of symmetry of the warhead, and results in an imperfectly formed jet at the standoff of the intercept.

Non-Jet Producing Outcomes	Descriptions
Fragment Induced Reaction (FIR)	A fragment hit on the warhead causes a deflagration event. A jet is not formed for this outcome. The reaction occurs fast enough that the warhead is consumed before impact with the vehicle.
Dud (DUD)	The threat does not detonate at intercept and cannot detonate normally upon hitting the vehicle due to fragment damage.
Dismembered Warhead (DWH)	Severe mechanical damage to the high explosive, the liner, or the physical structure of the round, results in the round being incapable of harming the vehicle.
Crush-Up	Not an direct outcome, but a secondary result of a DUD or a DWH interaction with armor. Sometimes, an intercepted threat that appears to have been defeated by an APS, detonates on the target, with no SC jet formation. This detonation can present problems for certain vehicles.

Background

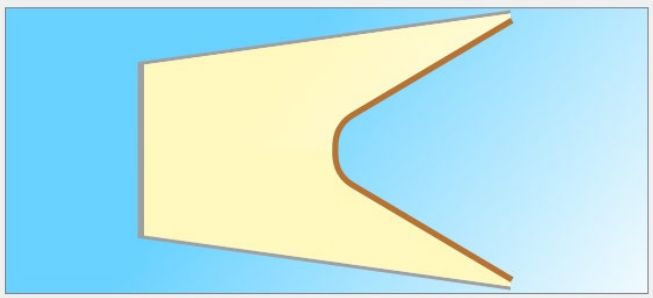
- SC3D - Survice Grown - primarily a design tool
- SC vs RHA/STEEL armor
- Single shot target analysis
- Extensively used by NSWC for Ship S/V
- Jet Breakup from incoherent SC at standoff



Background

- IRAD added utilities to SC3D for Residual Damage from SC EINJ
  - Penetration through composite armor
    - RHA Equivalence for Traditional Vulnerability Assessments
  - Component/Occupant Vulnerability
    - Pk given a CM intercept
      - Single Burst Point; Monte Carlo
    - Pk given a launch
      - HK-APS CM intercept geometric dome given launch
      - CEP and Monte Carlo

RHA Equivalence of Composite Armor Sample Exercise



Other Parameters

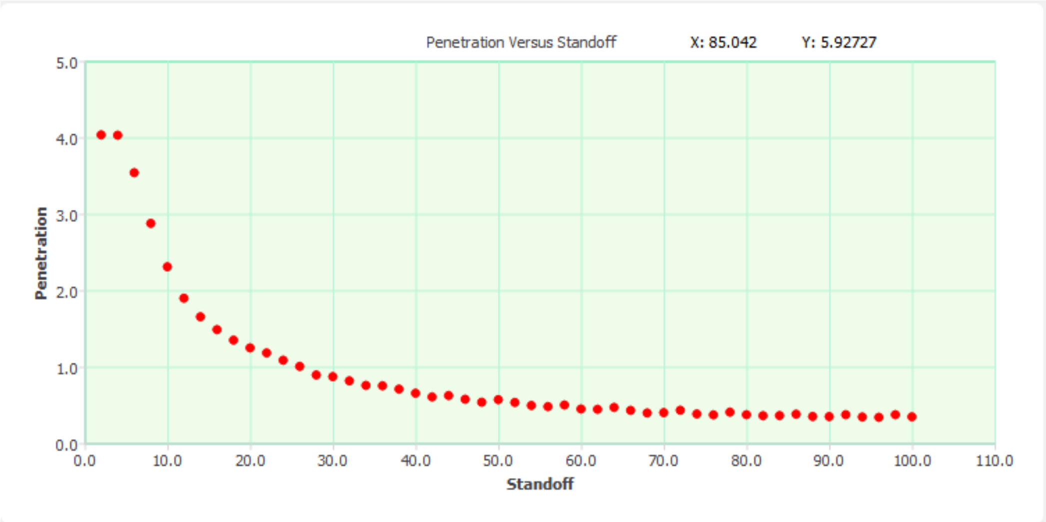
Initiation Point (X) cm.	7.209
Initiation Point (Y) cm.	2.48
Liner Density g/cc	8.93
Body Density g/cc	2.7
Cp	0.0149
Breakup Std. dev. usec	50
Sound Speed cm/usec	0.39
No. Jet Particles	49
Min. Drift Speed cm/usec	0
Max. Drift Speed cm/usec	0.007
Min. Tumble deg/sec	0
Max. Tumble deg/sec	45000

H.E. Properties

Density g/cc	1.58
CJ Pressure Mbar.	0.255
Det. Speed cm/usec	0.81
Internal Energy Mbar/cc	0.075
Ideal Gas Constant	2.7

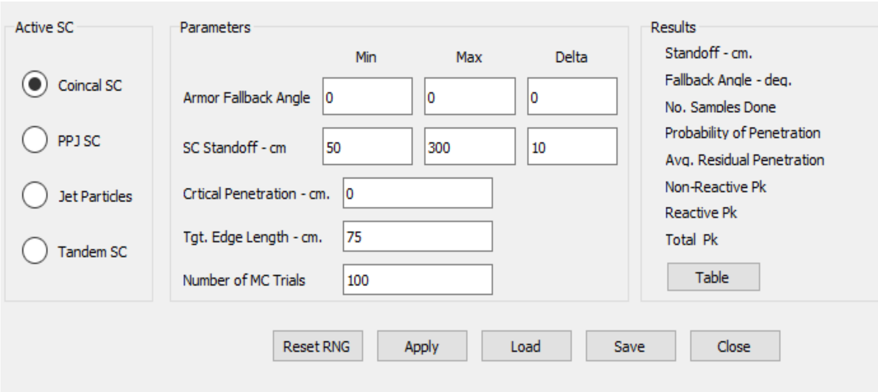
Scale Factor

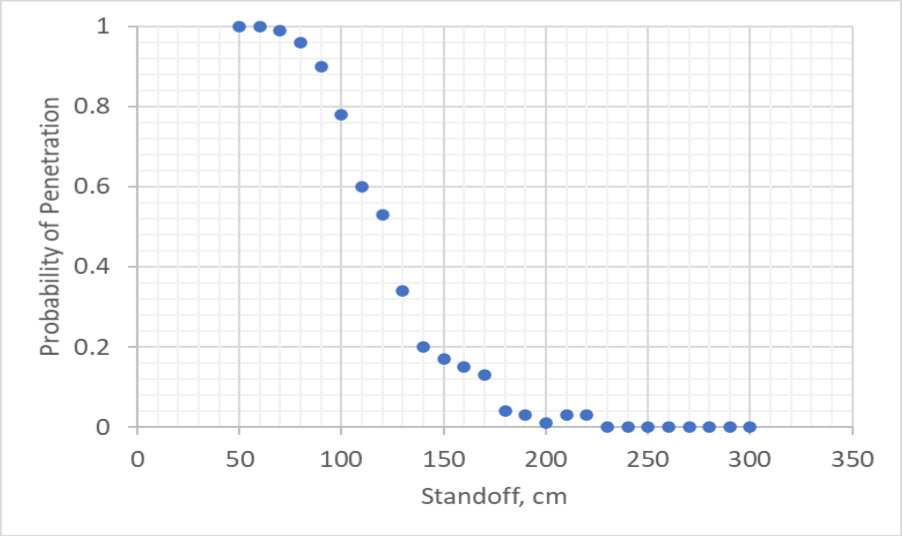
Apply Scale Factor



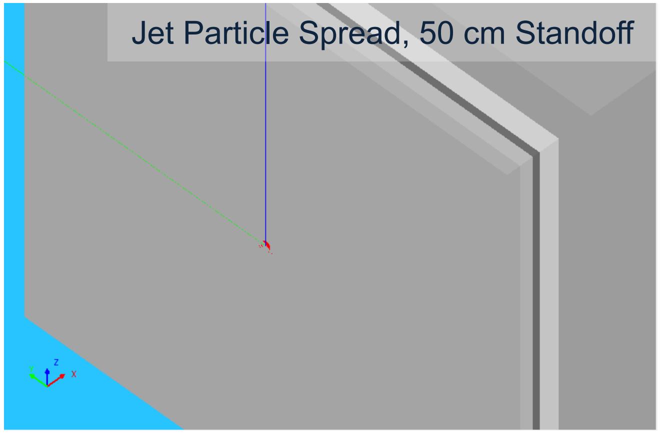
RHA Equivalence of Composite Armor Sample Exercise

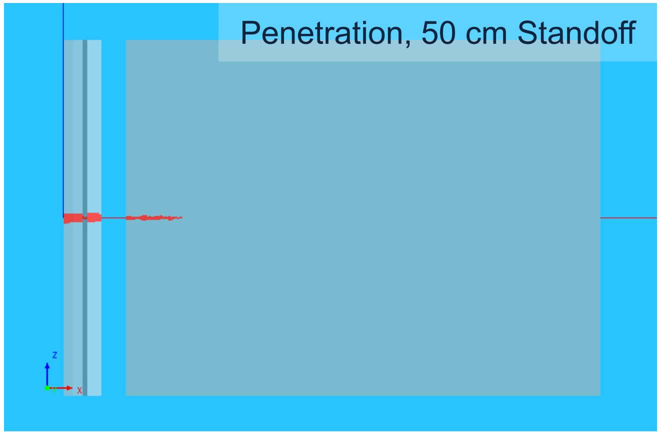
Name	Density g/cc	Dynamic Yield mbar
Ceramic	3.5	0.022
Aluminum	2.7	0.017
RHA-HH	7.84	0.35
Fabric	1.2	0.001

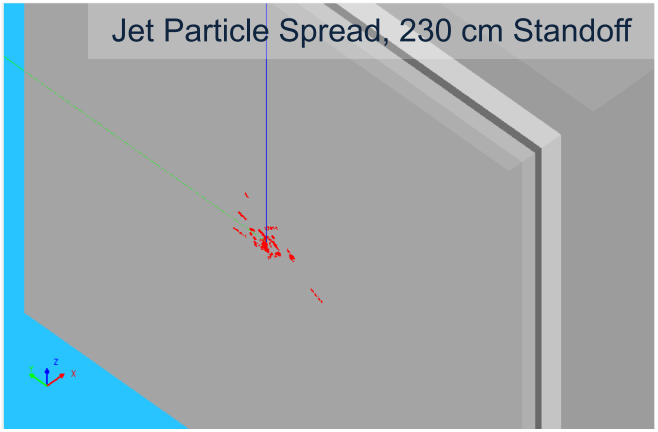


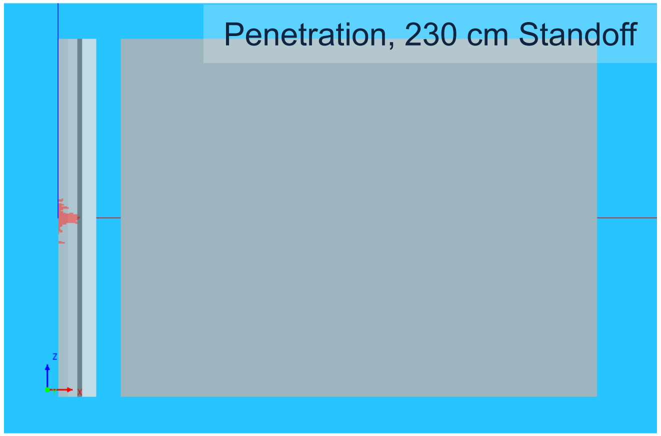


RHA Equivalence of Composite Armor Sample Exercise

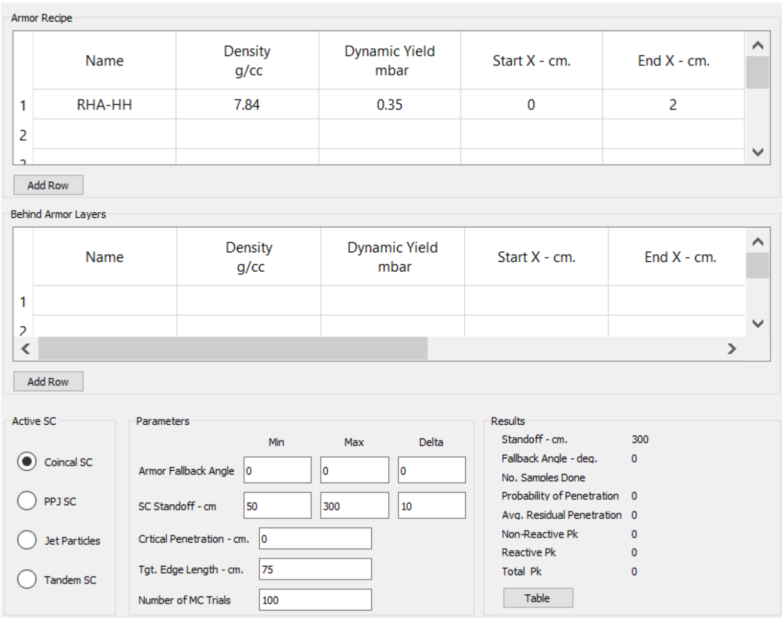




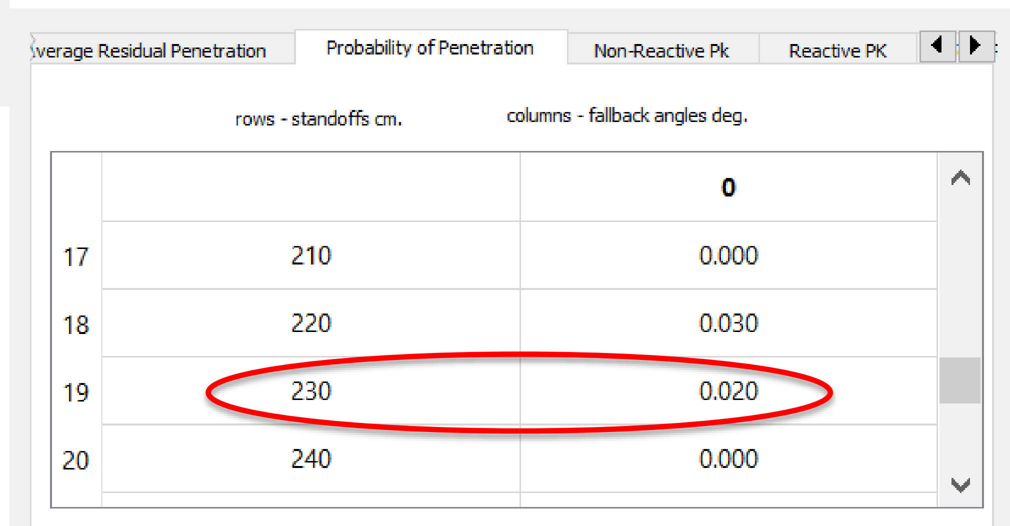




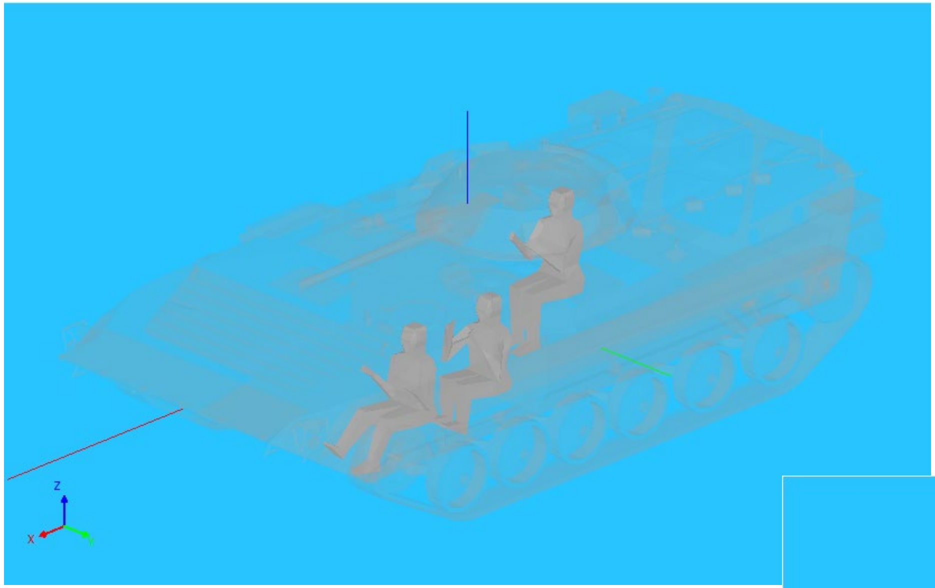
RHA Equivalence of Composite Armor Sample Exercise



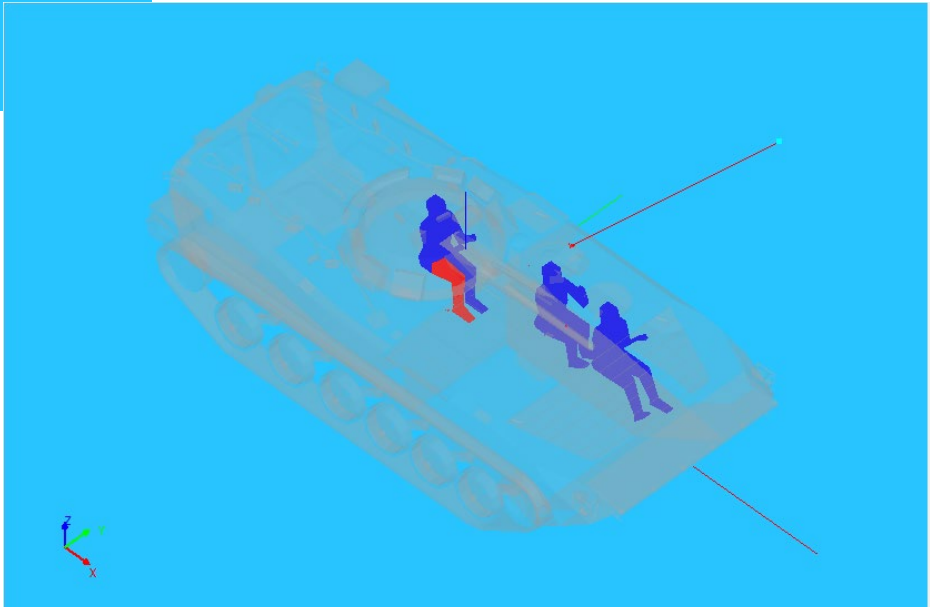
- Run SC3D at different RHA thicknesses
- Find RHA thickness that produces zero probability of penetration at the same standoff as the hypothetical armor recipe (230 cm in this example)
- In this case, the RHA equivalence of the hypothetical armor recipe was found to be 2 cm.



Occupant Vulnerability Single CM Intercept



- Sample target vehicle geometry (BMP2).
- Occupants set as vulnerable components. No fault tree.
- Component kill at 0.1 cm/µsec



- Singular EINJ event
- 80 mm diameter threat.
- Intercept at roughly five meters from the vehicle.
- Jet modeled with break up, tumbling particles with radial velocity.
- Monte Carlo runs set to 50.

Occupant Vulnerability Pk Given a Launch

Rayleigh Distribution generating a Circle Error Probable (CEP) on a hemisphere that is the assumed geometry of CM threat intercept. APS offers a “protection dome.”

Given a launch and the inherent probability of the threat intersecting anywhere on the CEP, the Pk of vulnerable components can be calculated.

The equation for the cumulative distribution function for a Rayleigh distribution contains one parameter: σ. One CEP is 1.17 σ.

$$F(x) = 1 - e^{-x^2/2\sigma^2}$$

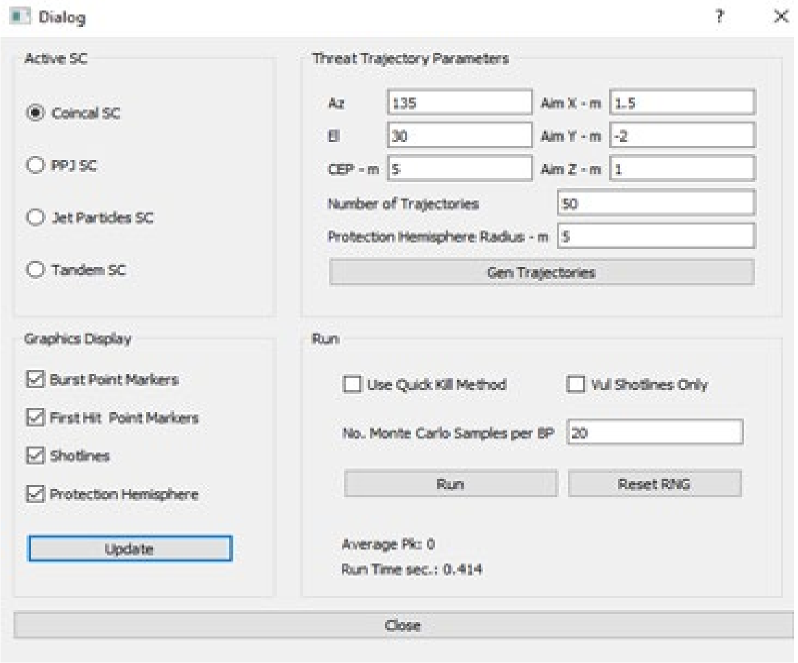
Statistical spread of where the threat might actually go vs. what was being aimed for (the CEP).

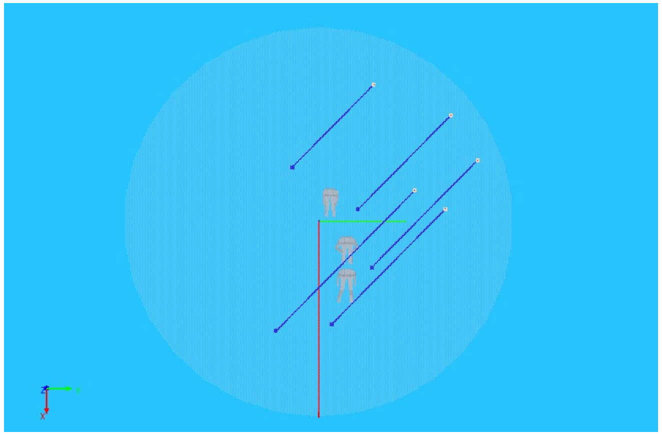
At each probable intercept, a Monte Carlo is run among the Rayleigh distribution of intercepts.

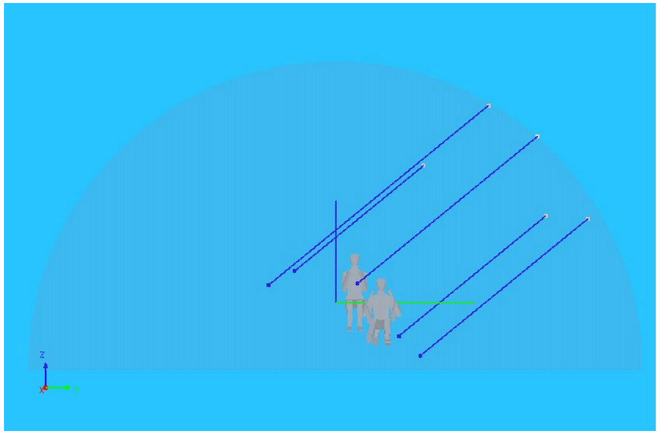
Same target and threat used previously

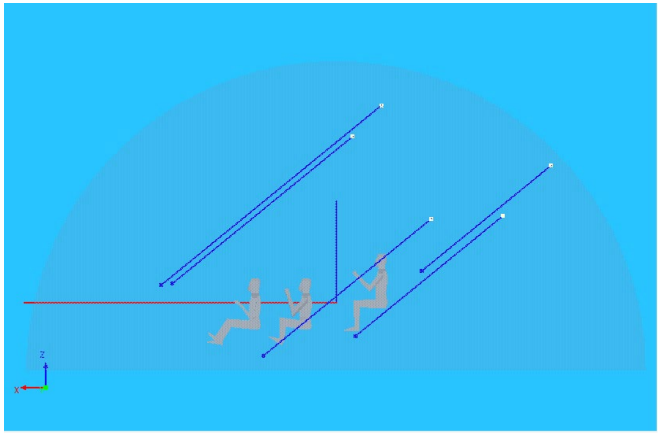
Select aimpoint, attack Az/El.

Occupant Vulnerability Pk Given a Launch









Conclusion

- SC3D
- Calculate penetration against armor recipes that include fabric and ceramics
  - RHA Equivalence
- Evaluation of Occupant Vulnerability from EINJ
  - Single Burst
  - CM engagement probability given launch
- Better methodology towards quantifying HK-APS performance