2020 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
SURVIVABILITY TECHNICAL SESSION
AUGUST 11-13, 2020 - NOVI, MICHIGAN

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

Alex Bernardo[1], Pat Buckley[2]

[1]Survice Engineering Co., WAO, Dumfries, VA
[2]Survice Engineering Co., PMC, Albuquerque, NM

ABSTRACT

The main aspect of this investigation is the fast calculation of jet break-up from incoherent shape charge effects on targets. Several examples are used to verify force protection with Hard Kill Active Protection Systems. The first example showed how SC3D can be used to estimate the RHA equivalence of a layered armor recipe against a shape charge threat at standoff. The RHA equivalence can then be used in traditional vulnerability assessments. In the second example, a stochastic analysis was done of an Early Initiated Normal Jet event against a target vehicle to evaluate occupant survivability. Although Monte Carlo was used to calculate vulnerability, this was representative of a singular, deterministic HK-APS intercept of a threat (Pk given an intercept). In the third example, an additional layer of stochastic analysis evaluated probability of intercept, accounting for Circle Error Probable of a threat as it is intercepted by an APS along a protection hemisphere. The resulting Pk is therefore that given a launch.

Citation: A. Bernardo, P. Buckley, "Applying SC3D to Verify Force Protection with Hard Kill Active Protection Systems", In Proceedings of the Ground Vehicle Systems Engineering and Technology Symposium (GVSETS), NDIA, Novi, MI, Aug. 11-13, 2020.

1. INTRODUCTION

Survice Engineering Co. has been involved in exploring Active Protection Systems for the United States Marine Corp. (USMC). Under an Internal Research and Development Effort, recent improvements have been made to SC3D, a Survice-developed shape charge analysis code. The penetration model in SC3D follows in the line summarized in [1], as well as other references. In order to assess an effective Hard Kill Active Protection System (HK-APS), a performance metric to understand is the amount of residual damage when the HK-APS engages the threat with its explosive countermeasure (CM) [2]. Ideally, the CM neutralizes the shape charge using blast effects. In less than ideal circumstances, one of a number of outcomes can occur that can still produce a jet. The deadliest event is when the warhead initiates normally upon impact without being damaged by the CM. Another potential event, often observed in HK-APS testing, is when the warhead initiates normally at the CM-intercept-standoff with no damage to the warhead and produces a normal jet. This outcome, called Early Initiation with Normal Jet (EINJ), is what we will focus on. Understanding residual damage from EINJ directly leads to quantifying ground vehicle vulnerability and force protection on a combat ground vehicle that implements HK-APS. Tools such as AJEM, COVART and TurboPK rely on computational ray tracing through shielding, armor, or vulnerable components to determine vulnerability. While work has been done to characterize EINJ on RHA [3], using SC3D to characterize EINJ on vehicles that have composite armor systems other than pure RHA, like the ACV and Stryker, is a stopgap available right now, as RHA equivalence must be determined for those more exotic systems. One would think that this gap could be filled by hydrocode, but by its very nature, modeling the incoherent jet associated with EINJ is imperfect.

SC3D analytically models the radially expanding jet phenomena, the effects of which are pronounced with EINJ against light composite armor.

In this paper, a hypothetical composite armor is investigated for residual damage effects as a function of standoff. SC3D automatically tabulates probability of penetration over a range of standoff and over a range of armor fallback angles, wherein each condition, the number of Monte Carlo runs can be specified. During a parametric run, SC3D provides visualization of resulting craters and penetrations on the target from the jet particles. An additional feature is the capability to run animation of a specific problem case.

The following steps can be taken to determine the RHA equivalent of a composite armor recipe:

- A hypothetical composite armor recipe is input into SC3D, including properties and thicknesses.
- A predefined shape charge is loaded from a file.
- A parametric run is specified to determine at what standoff the shape charge must be located to bring the probability of penetration down to zero.
- A second instance of SC3D is booted for the same shape charge.
- An iteration is conducted of RHA thicknesses run through the same parametric process until an equivalent RHA thickness is determined.

Once the RHA equivalence has been found, traditional vulnerability assessments can be done.

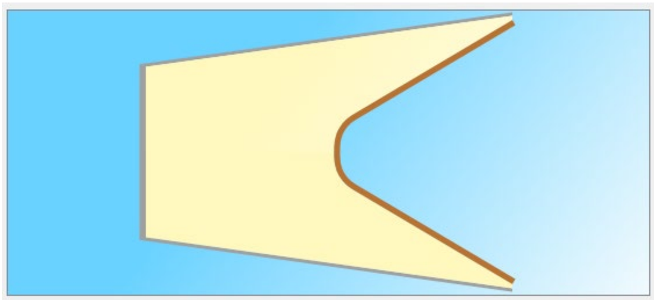
2. OBTAIN RHA EQUIVALENCE OF A COMPOSITE ARMOR--EXAMPLE

For this example, a hypothetical light composite armor comprised of four layers is analyzed to determine RHA equivalence, Figure 1. This example is not meant to be an optimized armor solution.

Name	Density g/cc	Dynamic Yield mbar	Start X - cm.	End X - cm.
Ceramic	3.5	0.022	0	2
Aluminum	2.7	0.017	2.01	4.01
RHA-HH	7.84	0.35	4.02	5.02
Fabric	1.2	0.001	5.03	8.03

Figure 1: Hypothetical Layered Composite Armor Recipe Input into SC3D.

The shape charge of interest is nominally 80 mm in diameter; geometry is entered as piecewise input, along with other parameters, Figure 2. The statistical range of particle tumble velocity and particle drift speed is set in the threat input. Shape charge behavior is quickly calculated, in particular jet break up and tumbling characteristic of incoherent jet formation, in addition to usual properties such as Penetration versus Stand Off (PVSO), not shown.



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

Figure 2: Sample Shape Charge Geometry (80 mm diam.) and Input Parameters for SC3D.

A parametric run, in this case, is done to identify the standoff distance where there is zero probability of penetration. This example is set up to determine penetration at 0° obliquity, making penetration calculations from standoff values from 50 cm to 300 cm, where for each case 100 calculations were run in Monte Carlo. Calculation results generate a table of standoff distance versus probability of penetration, where it was found zero probability was at 230 cm standoff (several runs were made to confirm, since Monte Carlo is being implemented), Figure 3.

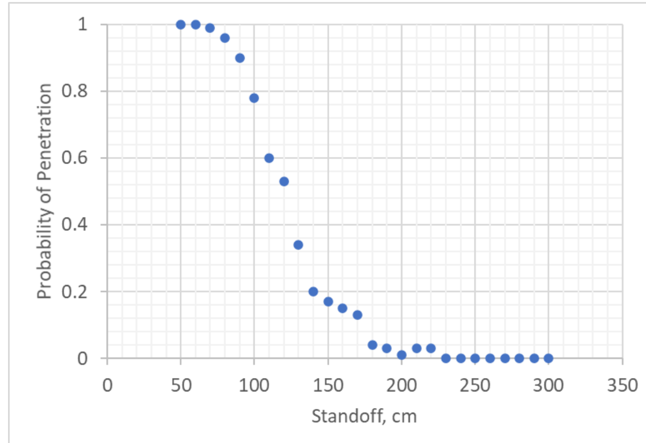


Figure 3: Results of Parametric Run Showing Probability of Penetration as a Function of Standoff for a Hypothetical Armor Recipe.

When doing a parametric study, SC3D will animate each case, marching through the chosen range of standoff and fall back angle. Figures 4a through 4d shows some graphics of the armor penetration. The animation is chosen from one of the Monte Carlo scenarios, the number of which is user specified.

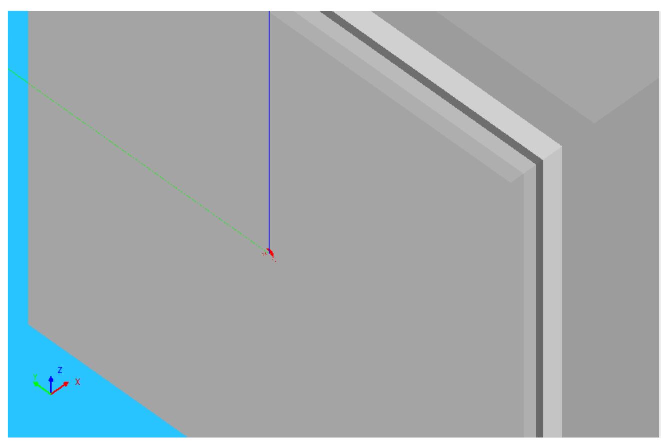


Figure 4a: Jet Particle Spread at 50 cm Standoff of 80 mm Diameter Shape Charge.

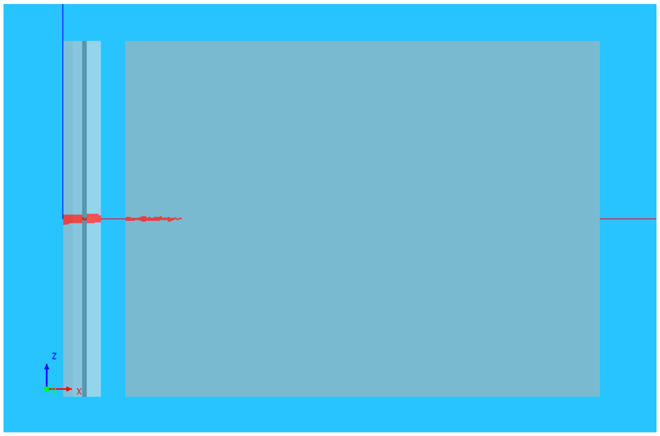


Figure 4b: Penetration of 80 mm Diameter Shape Charge Through Hypothetical Armor Recipe into RHA Slab at 50 cm Standoff.

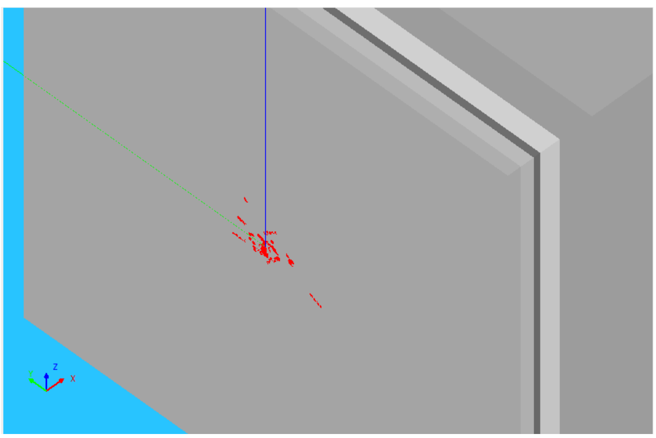


Figure 4c: Jet Particle Spread at 230 cm Standoff of 80 mm Diameter Shape Charge.

Figure 4d: Penetration (none) of 80 mm Diameter Shape Charge Through Hypothetical Armor Recipe into RHA Slab at 230 cm Standoff.

RHA equivalence was determined by iterating towards a thickness of RHA that produced zero probability of penetration at the same standoff as the hypothetical armor recipe. A second instance of SC3D was booted to do this, conducting runs where all input parameters were kept constant except the armor recipe, which was changed to just RHA. The thickness of the RHA was changed and the parametric analysis was run until calculations resulted in zero penetration probability at standoff of 230 cm. In this case, the RHA equivalence of the hypothetical armor recipe was found to be 2 cm.

One can correctly presume that analysis can be conducted to optimize an armor recipe by areal density, by trying different combinations of materials and corresponding thicknesses, leading to a desired RHA equivalence.

3. OCCUPANT VULNERABILITY

Using SC3D, vehicle occupant vulnerability from an EINJ event can be examined by setting occupants as vulnerable components. A sample target vehicle geometry (BMP2) that includes occupants was analyzed to find level of force protection, Figure 5. The threat was the same 80 mm diameter as in the previous example.

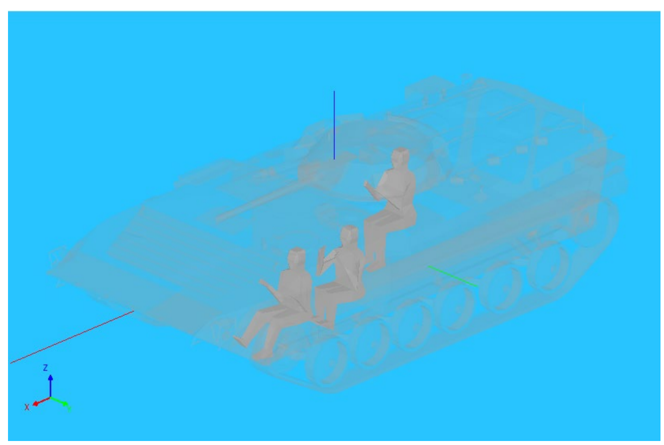


Figure 5: Sample Target Vehicle Geometry (BMP2) with Occupants set as Vulnerable Components.

The shape charge was set to initiate early at roughly five meters from the vehicle, a likely intercept distance from an APS such as the Rheinmetall AMAP-ADS. The jet is modeled to have broken up, particles tumbling with radial velocity. A simple result is shown in Figure 6, where an occupant is struck. The number of Monte Carlo runs was set to 50 in this example to obtain the result. In this sample run, a component kill was set at 0.1 cm/μsec and no fault tree was implemented.

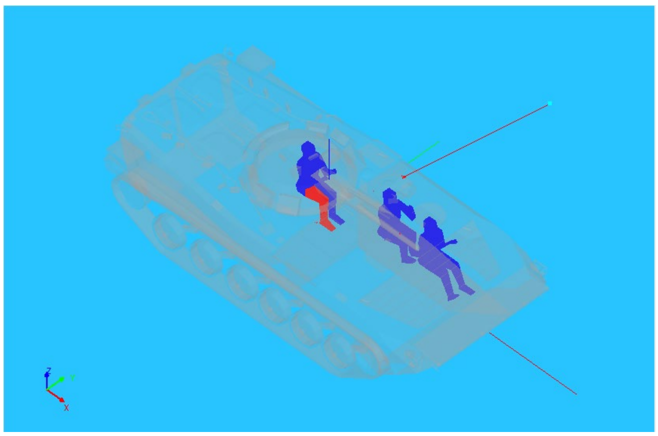


Figure 6: Single EINJ Event Against a Target Showing Occupant Vulnerability. Green dot is Initiation Point.

If it is desired to evaluate an armor recipe on a target component, then one would use the RHA equivalent.

Above is a quantification of component Pk given a single hit (intercept). To gain greater insight into Pk *given a launch*, SC3D has additional provision to stochastically analyze a scenario when a threat has been launched at an aimpoint on the target. The method uses a Rayleigh Distribution generating a Circle Error Probable (CEP) on a hemisphere that is the assumed geometry of CM threat intercept. The 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 (1) for the cumulative distribution function for a Rayleigh distribution contains one parameter: σ. One CEP is 1.17 σ.

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

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

With the same target and threat used previously, an aimpoint is selected along with Az/El. Parameters are also specified that are associated with the statistical spread of where the threat might actually go vs. what was being aimed for (the CEP). See Figures 7a – 7d. In this instance, owing to the CEP, standoff, and inherent shape charge incoherence, the Pk = 0.

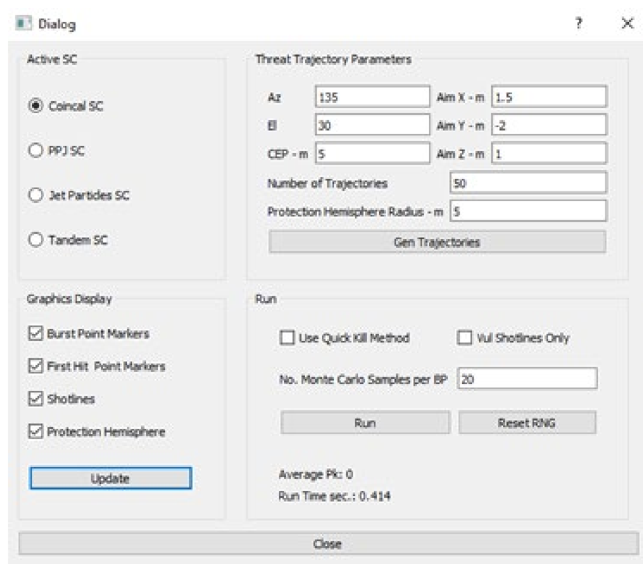


Figure 7a: Input Parameters and Result, APS Protection Hemisphere vs. Threat.

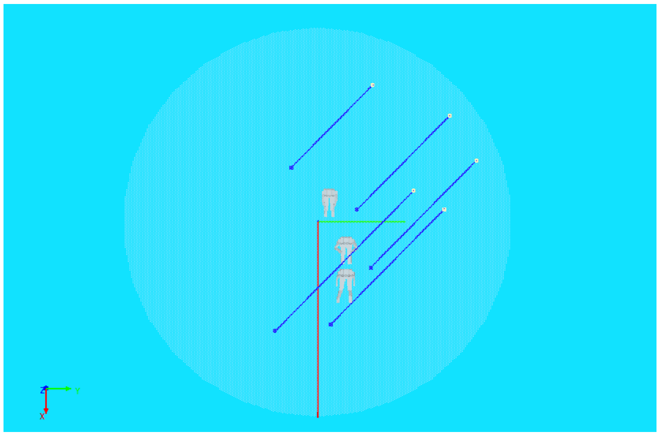


Figure 7b: APS Protection Dome vs. Shape Charge Threat. Top View. CEP about Aimpoint.

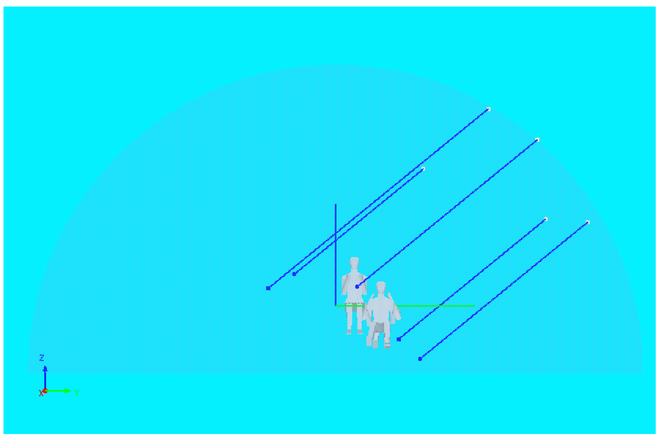


Figure 7c: APS Protection Dome vs. Shape Charge Threat. Front View. CEP about Aimpoint.

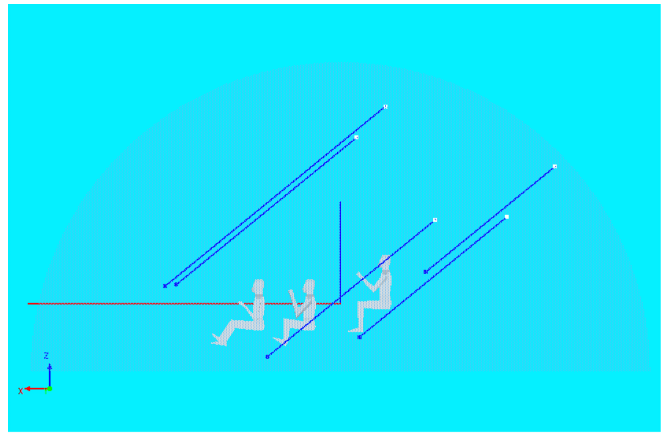


Figure 7d: APS Protection Dome vs. Shape Charge Threat. Side View. CEP about an Aimpoint.

4. CLOSING REMARKS

SC3D has been improved to calculate penetration against armor recipes that include fabric and ceramics. Its capability lends itself to evaluating residual damage from the Early Initiated Normal Jet phenomenon that occurs when a Hard-Kill Active Protection System countermeasure intercepts a shape charge threat.

1. REFERENCES

[1] P. J. Hazell, "Armour: Materials, Theory, and Design" CRC Press, July 29, 2015.

[2] STANAG (STANdardization AGreement) 4686, Performance Levels of Defensive Aids Suites (DAS) for Armoured Vehicles, 11/22/2012/AEP (Allied Engineering Publication) 62, DAS Threat Classification, 6/7/2013

[3] J. R. Auten, P. Holman, and A. Ross, "Modeling of Shaped Charge Jets at Long Standoff in the Advanced Joint Effectiveness Model (AJEM)", ARL-TR-8708, June 2019