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ADVANCED MULTIPLE IMPACT ENDGAME MODEL AGAINST BALLISTIC MISSILE PAYLOADS

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A first principle multiple impact model has been incorporated into the RAYSCAN 3-dimensional endgame simulation. This new model concept attempts to make endgame codes more like hydrocodes taking into account cumulative damage effects. A new multiple impact model is developed which accounts for temporal spaced impacts as well as impacts from closely spaced projectiles. Ballistic missile payloads are being generated using small plate elements. If a projectile penetrates a small target element, then the element is removed from the calculation. A temporal spaced projectile that impacts within the initial crater diameter now benefits from the initial penetration from the first projectile. Hydrocode modeling was used to calculate the increased penetration from projectiles that are spaced very close. Projectiles that impact side-by-side penetrate somewhat like a single larger mass. However, as this spacing is increased there is less penetration enhancement until each projectile acts as an independent event. These ideas and logic have been incorporated into the simulation to predict more accuracy damage from near miss warhead technology.

OVERVIEW

Endgame simulations are widely used to assess the damage from kinetic energy penetrators. The damage inflicted to the target is a strong function of impact velocity, mass, density and obliquity angle. Endgame codes do provide some level of weapon lethality or figure of merit when comparing warhead concepts. These codes raytrace each projectile singly through the target not taking into account damage from closely spaced projectiles. New warhead technologies that generate projectile spacing that is close require new multiple impact damage methodologies. These new types of warheads require new endgame logic to model the enhanced damage from sequential and temporal spaced impacts. A description of the spray pattern density from an aimable rod warhead is shown in Fig. 1.

These combined interactions are currently modeled with hydrocodes taking full credit of multiple impacts with close spacing. However, these large runs are challenging and require many particles or cells to predict damage accurately. An example of a SPHINX hydrocode calculation is shown in Fig. 2.

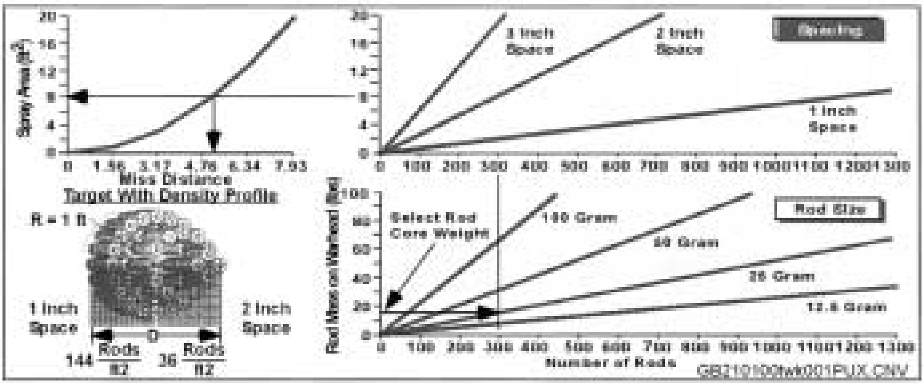

Figure 1. High Spray Density on Ballistic Missile Payload.

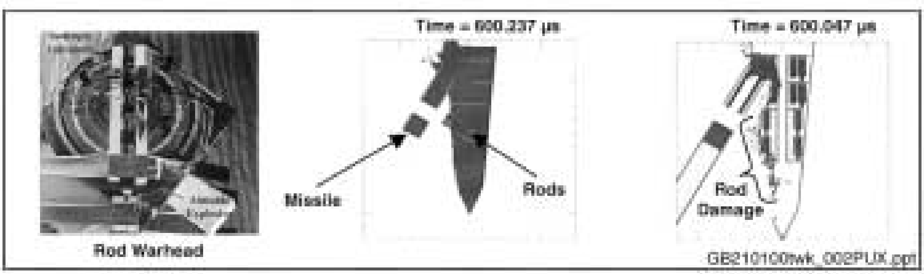

Figure 2. Sphinx Hydrocone Calculation Showing Cumulative Damage.

RAYSCAN MODELING AGAINST BALLISTIC MISSILES

The RAYSCAN endgame simulation has a new first order damage prediction technique to predict multiple impact effects from highly dense clouds of projectiles. This new model attempts to predict more accurately the damage from near miss or direct hit warhead technology against submunitions on ballistic missiles.

The multiple impact routine developed for RAYSCAN consists of two models. The first model accounts for temporal spaced projectiles. This technique allows for enhanced damage from deeper penetration because the projectile makes a crater allowing a second projectile to travel through the plate with no resistance. The second projectile continues on and penetrates deeper into the target utilizing the benefit from the first projectile. This concept is illustrated in Fig. 3.

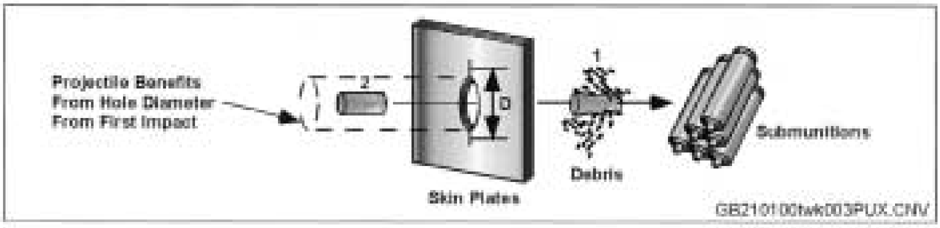

Figure 3. Follow penetration enhancement damage concept.

The second technique addresses simultaneous multiple impacts which accounts for added penetration potential. If two projectiles impact at the same time and are next to each other, then it could be said the initial mass is now twice the original mass. The total penetration has increased, and the penetration begins to decrease as a function of fragment separation distance. An example of this simultaneous impact is shown in Fig. 4.

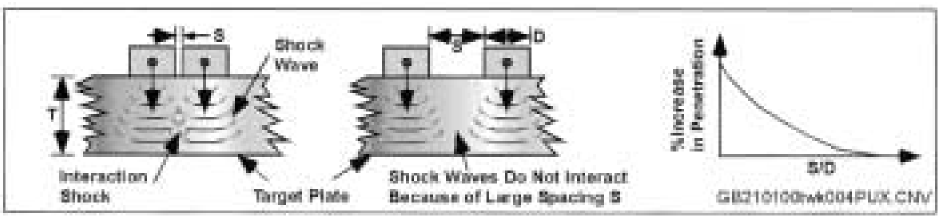

Figure 4. Enhanced penetration based on fragment spacing S.

A theoretical probability equation is used to determine the total number of multiple impact occurrences that may exist. The probability that a projectile will impact near another is predicted by

$$P_O = e^{-\xi}\, \xi^k / k! \qquad (1)$$

Where P_O is the probability of exactly N impacts per crater, ξ, equals the number of impacts multiplied by the impact crater divided by the total rod cloud area. So, let $\xi = AN_C/A_T$ and if the crater radius is 1 inch and the diameter of the spray pattern is 24 inches, then given 300 projectiles the probability of two projectiles impacting within a rod crater is 27 percent. The probability that three rods impact within a crater is 18 percent.

ELEMENT METHODOLOGY

The ballistic missile skin and submunitions are constructed using small plate elements. The element size is directly related to the projectile size and crater diameters. These damaged elements are deleted form the calculation allowing time delayed or temporal spaced projectiles to penetrate with the benefit from the first impact. The first step is to compute the diameter of the hole produced by the projectile penetration. The area of the target hole (Af) is computed by

$$A_f = A_p \left[1 + \phi\left(V_I - 1000\right)\right]^2 \sec\theta \tag{2}$$

where ϕ is a constant. The average presented area of the projectile at impact is A_p while the hole diameter d_c is equal to $d_c = 0.5\,(A_f/\pi)^{1/2}$. This calculation is performed initially before element deleting is initiated, see Fig. 5.

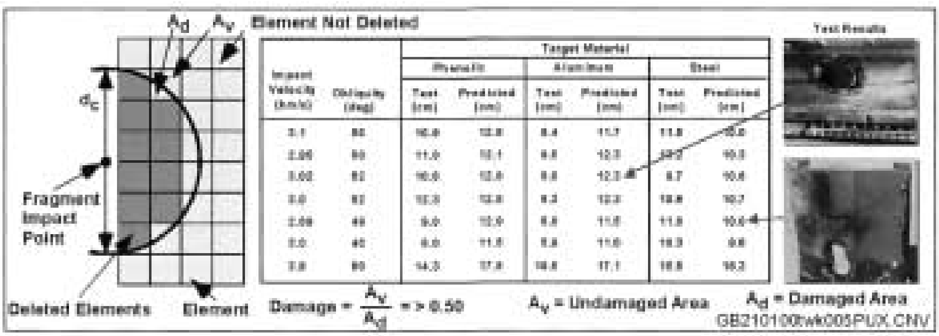

Figure 5. Boundary conditions delete concept with test correlation.

The equation predicted entrance hole diameters reasonably well at very high impact velocities. Mat-projector testing was performed to investigate multiple impact effects against ballistic missile skins. The Mat-projector consisted of many metallic fragments backed by explosive. The fragments were accelerated near 8000 F/S. Behind the target plates were soft recovery bundles to safety catch the residual mass after penetration. The RAYSCAN endgame code was used to model the skin and a study different element sizes. The elements were initially 1.66 and 5 inch square plates. The 1.66 inch plates were smaller compared to the actual hole diameter while the 5 inch square plates were near or slightly larger then the hole diameter. The RAYSCAN simulation was run and a similar spray pattern was placed on the target compared to the tests. An illustration of the test and both RAYSCAN calculations are shown in Fig. 6.

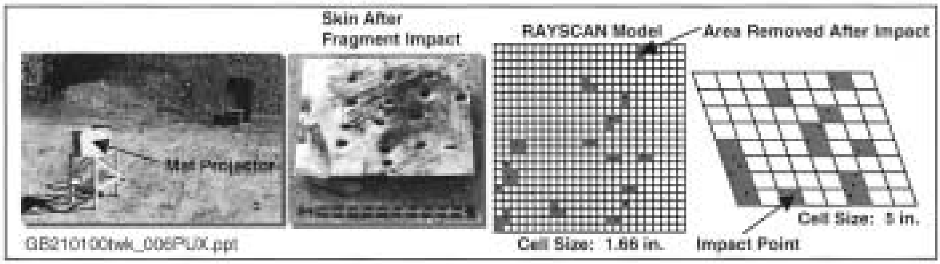

Figure 6. Comparison between rayscan calculation and multiple impact testing against ballistics missile skins.

The hole dimensions of each impact was near 3 inches in diameter. The 1.66 inch element model produced more accorate predictions of the total area removed from the skin compared to the 5 inch element. The total area of the test plate is 1600 square-inches. The small 1.66 inch grid removed approximately 101.9 square-inches of area leaving 1498 square-inches. This equals an error of 1.26percent. However, as ex-pected when large elements are usod, there is only the area of the plate that is removed. The hole diameter from these tests was not large enough to encompass an adjacent plate. The total area removed was 65 square-inches leaving a total area of 1535 square-inches. This larger element size left 3.6 percent more target area relative to the test. These differences in area may not appear large, however, the area that is not removed could cause fragments to impact areas that were removed from the calculation that should not. Temporally spaced projectiles would gain the benefit from large elements. This potential concern is illustrated in Fig. 7.

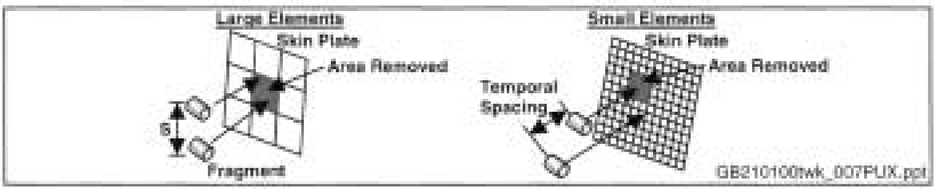

Figure 7. Large elements removed allowing less resistance.

SIMULTANEOUS IMPACTS

New penetration logic was derived to compute penetration from projectiles that are closely spaced. A modified technique developed by Zernow and Piechocki to predict enhanced penetration from shock interactions from simultaneous impacts of two projectiles is presented. If two fragments do not impact at the same time then they are considered temporal spaced impacts. However, if two fragments impact a plate at the same time there is a potential increase in overall penetration as a function of spacing. Obviously, as the spacing increases there is less shock interactions between both fragments. The penetration of both fragments is now only equal to the penetration of a single fragment. A model has been incorporated into RAYSCAN endgame code to compute the enhanced penetration from closely spaced projectiles. Consider a plate that is impacted by two fragments in Fig. 8.

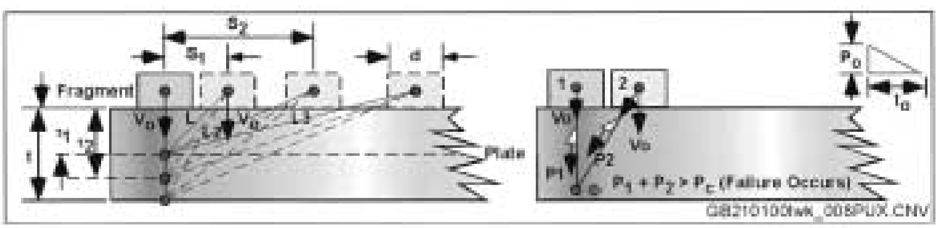

Figure 8. Relation between shock and multiple impact.

There exists a combined shock wave from two projectiles that impact a plate when they are closely spaced. There is a change in the pressure profile acting against the back face of the target plate. The pressure profile of a single fragment penetrating a thin plate can be calculated. If two simultaneous impacts create a combined pressure equaling the required pressure to penetrate the plate before arriving at the back surface, then added penetration from the multiple impacts occurs. A mathematical model can be used to determine the percent increase in penetration as a function of fragment spacing.

The HULL hydrocode was used to investigate the combined pressure from multiple impacting fragments. The difference in penetration was correlated to fragment spacing. A comparison between penetration at 0.1D and 0.3D is illustrated in Fig. 9.

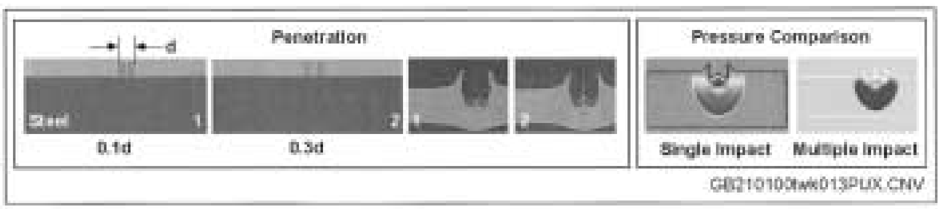

Figure 9. Hull hydrocone calculation of penetration.

The multiple impact hydrocode calculations showed deeper penetration and large bulges on the aft side of target plates. If a thinner plate were used, then the material would have spalled or broke off allowing the projectile to penetrate. A pressure calculation is also shown between two different spaced impacts. There is a significant increased in pressure from the closely spaced projectiles.

The projectile density is ρ while V_0 is the initial impact velocity. The pressure pulse is assumed to be triangular and the pressure from the first fragment is

$$P_1 = P_o e^{\beta L} e^{-\lambda (L-\tau)} = P_o e^{-\left(\sqrt{\tau^2+S^2}/2.5\,d\right)} e^{-1/0.6\,d\left(\sqrt{S^2-\tau^2}-\tau\right)} \tag{3}$$

where τ is the plate depth in question and d is the fragment diameter. The spacing between fragments is distance S. The second fragment impacts with pressure profile P_2 is

$$P_2 = P_o e^{\beta L} = P_o e^{-\left(\sqrt{\tau^2+S^2}/2.5\,d\right)} \tag{4}$$

where, if the head of shock wave of fragment 2 intercepts with wave 1, before wave 1 impacts the back surface, the total pressure is

$$P_1 + P_2 = P_o e^{-\left(\sqrt{\tau^2-S^2}/2.5\,d\right)} \left(1 + e^{-1/0.6\,d\left(\sqrt{S^2-\tau^2}-\tau\right)}\right) \tag{5}$$

The interaction of these shocks occur at distance τ at point ϕ. The critical pressure at point ϕ for a single fragment penetration is

$$P_c = P_o^{-(1/2.5\,d)-\left(t-\sqrt{\tau^2+S^2}\;+\tau\right)} \tag{6}$$

If $P_1 + P_2 \geq P_c$, then the plate would have been perforated at that point in the plate. This fraction increase in penetration is multiplied to the total penetration equation relative to a single penetration calculation. The RAYSCAN code is now able to calculate enhanced damage from projectiles that are closely spaced.

SUBMUNITION MODELING CONCEPTS

A first order multiple impact model was developed to investigate the lethality of temporal spaced projectiles against a multitiered submunition payload. The initial penetration equations and element technology is applied to investigate overall target damage. The first step is to correlate element size and limitations to the modeling approach.

A series of tests were performed to investigate the temporal spacing of multiple fragment impacts. The first test fired a single fragment into a pack of three submunitions while a second test fired another fragment with some small spacing. The RAYSCAN simulation predicted the same overall penetration and deleted the correct penetrated elements. An illustration of the RAYSCAN model of both these impacts is shown in Fig. 10.

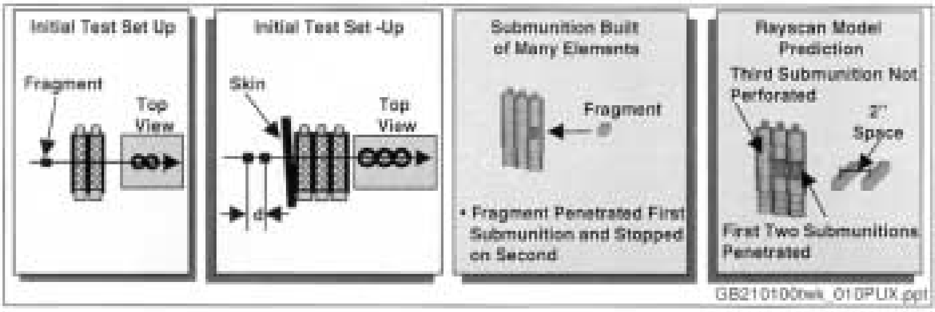

Figure 10. New model predicts temporal spaced test data.

These simple penetration tests into submunitions demonstrated that the current models could predict enhanced damage from temporal spaced projectiles. A full target payload test was performed where 225 tungsten cubes impacted a submunition payload.

The target was reconstructed showing most of the submunitions were totally blown apart or ruptured with single or multiple holes. The RAYSCAN model was employed and demonstrated test lethality with an accuracy of 5 percent. Nearly 90 percent of the payload was considered killed from this high energy impact. It is believed that small elements with new penetration logic can improve future calculation accuracy. An illustration of the RAYSCAN prediction with the damaged test target is shown in Fig. 11.

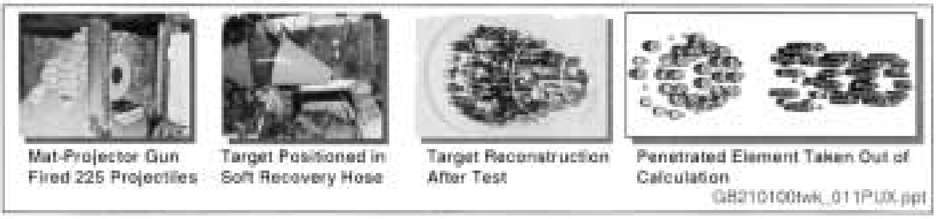

Figure 11. Damage comparison between rayscan and test.

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