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THREE-DIMENSIONAL ANALYSIS OF THE EXPLOSIVE INITIATION THRESHOLD FOR SIDE IMPACT ON A SHAPED CHARGE WARHEAD

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ABSTRACT

Prior analysis in two dimensions of the impact of fragment-simulating projectiles on a six-inch warhead suggested that initiation occurs after a significant delay. The simplifying but reasonable assumptions about the projectile and warhead shapes introduced uncertainty in the conclusions that could only be resolved by repeating the analysis in three dimensions.

The three-dimensional analysis reported herein confirms the conclusions of the earlier study, and it justifies the use of the simplifying assumptions for two-dimensional analysis for similar studies of impact.

The calculations were performed on PC's with the AUTODYN 2D™ and AUTODYN 3D™ codes using the Lee-Tarver ignition and growth model.

INTRODUCTION

Initiation threshold velocities were available from tests of 50 caliber fragment-simulating projectiles impacting a six-inch shaped charge warhead from the side.

For an earlier study of these threshold events (Davison, 1992b), analysis was limited to two dimensions (2D) because of cost constraints. For the 2D analysis, impact was assumed to be symmetric about the axis of impact (Figure 1). The chisel-shaped noses of the fragment-simulating projectiles (FSP's) were represented by truncated cones of appropriate cross-sectional areas, and the curvature of the body was ignored.

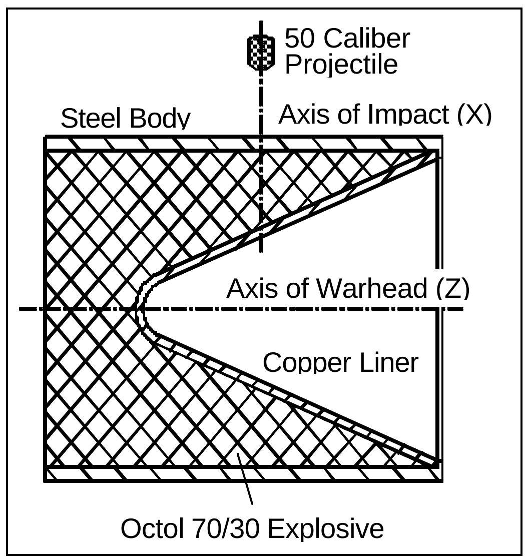

Figure 1. Six-inch warhead impacted by a 50 caliber fragment-simulating projectile.

For this study the projectiles and the warhead were modeled in three dimensions (3D). The chisel-shaped noses of the projectiles were accurately represented, as was the curvature of the warhead body. The calculations were made with two planes of symmetry: one, containing both the projectile ("X") axis and the warhead ("Z") axis, and the other, containing the projectile axis but perpendicular to the warhead axis. Limits on the thresholds were found, and two projectile alignments were examined: one with the "chisel" oriented along the warhead (“Z”) axis, and the other with the "chisel" oriented perpendicular to both these directions, aligned with the “Y” axis.

BACKGROUND

The previous calculations were made in 2D with simplifying assumptions about the shapes of the projectile and warhead. To adapt the projectile to the computational mesh of Figure 2, the chisel-shaped nose of the projectile was transformed into a circular region with an area equal to that of the chisel point (Figure 3).

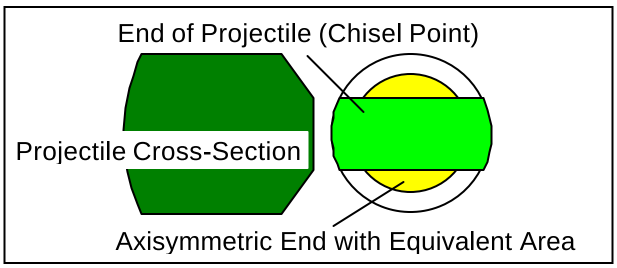

Figure 3. Simplified model of the projectile for the 2D analysis.

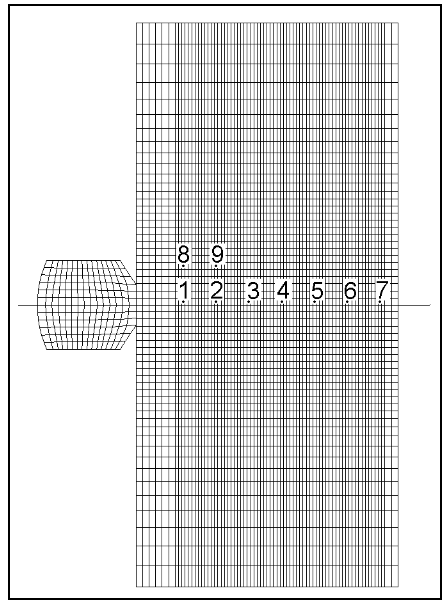

Figure 2. Computational mesh for the 2D analysis.

The prior analysis indicated that a cell size of 0.050 cm for the explosive would be acceptable; hence this was the cell size in the 3D analysis.

For the analysis reported herein no simplifying assumptions about the shapes of the projectile and warhead were made, but the study was restricted to two limiting cases in which the projectile was aligned along the X-axis and impacted normal to the surface of the warhead’s body. For these cases, symmetries about two planes reduced the scale of the calculations by a factor of four by comparison to cases in which the projectile would be skew or would impact obliquely.

The objective of the analysis was to determine whether or not initiation would occur at early time (within a few microseconds), as a result of the impact shock transmitted into the explosive. Consequently, as before, a model of only a small segment of the warhead was required.

INITIATION MODEL

Version 3 of the AUTODYN codes include the ignition and growth model [(Lee & Tarver, 1980) and (Tarver et al., 1985)] as standard features. The implementation allows for treatment of the unreacted explosive with parameters from the shock equation of state (EOS), available for many explosives [e.g., Table 7-5 of (Dobratz & Crawford, 1985)], or with an EOS in the Jones-Wilkins-Lee (JWL) form.

The model for Octol 70/30 is listed in Appendix B of the *Users Guide/Modeling Explosive Initiation in AUTODYN* (Davison, 1997). The parameters for the shock unreacted EOS are from (Dobratz & Crawford, 1985); the parameters for the gaseous JWL EOS are from (Murphy, 1989); and those for the Lee-Tarver ignition and growth model are from (Davison, 1992a). The latter were derived from fits to the Pop plots (Ramsay & Popolato, 1980) for Octol 70/30. The shear modulus was derived from the density and sound speed in Table 7-6 of (Dobratz & Crawford, 1985), and the Von Mises yield strength was estimated from values at high strain rates for similar explosives.

RESULTS OF THE ANALYSIS

Four 3D calculations were made, parameterized as indicated in the following table:

Projectile Velocity V_x (cm/ms)	*Chisel Alignment*	*Explosive Initiated?*
0.16	Y-Axis	No
0.16	Z-Axis	No
0.18	Y-Axis	Yes
0.18	Z-Axis	Yes

The threshold for prompt initiation exceeded 0.16 cm/μs, greater than the observed value of 0.152 cm/μs, as was found with the two-dimensional analysis. Hence the former conclusion that initiation occurred after a significant delay, perhaps as a result of late-time compression of the explosive, was confirmed.

Figure 4 is a pair of plots of maximum pressure profiles for the row of cells adjacent to the X-axis, along which the projectile moved. The steps in the curves are at cell interfaces. For the impact at V_x = 0.18 cm/μs, two curves are shown, corresponding to the two chisel alignments. There is little difference between these curves, indicating that pressure and initiation is not sensitive to chisel alignment.

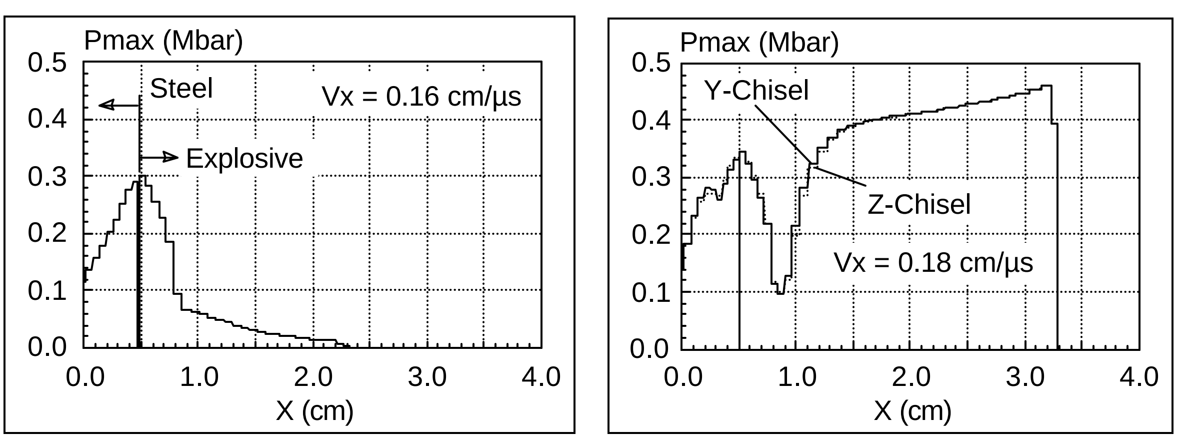

Figure 4. Profiles of maximum pressure in the interval t = 0 to 6 μs for the two velocities.

Figure 5 is a pair of plots of pressure histories for the two velocities. For the velocity $V_x = 0.16$ cm/µs, the pressure quickly fell to a very small value, but, for the velocity $V_x = 0.18$ cm/µs, the pressure rose quickly above the Chapman-Jouguet value of 0.320 Mbar and peaked above this value for subsequent points monitored.

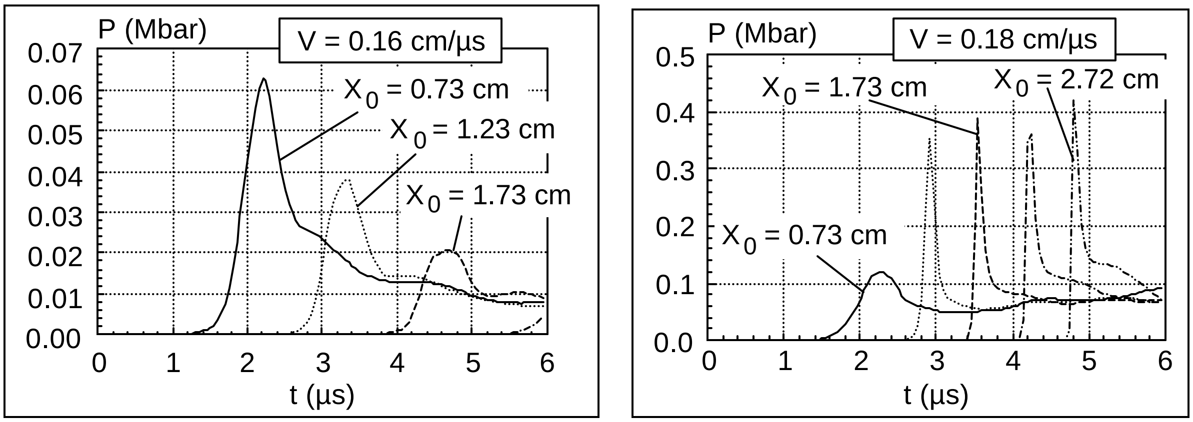

Figure 5. Pressure histories for the two velocities at points in the row of cells next to the X-axis. Note the change in scale for the two cases. Initial locations $X_0 = 0.73$ cm, 1.23 cm, etc., were at the same distances from the surface of warhead as were points monitored in the two-dimensional analysis (those marked 1, 2, etc., in Figure 2).

Figure 6 is a set of material and pressure contour plots for the two chisel alignments and a projectile velocity of $V_x = 0.16$ cm/µs. Note that the pressure levels form a geometric (non-linear) progression that brings out low-pressure details. Pressures are somewhat greater in the direction at right angles to the chisel alignment. Figure 7 is a set of pressure contour plots for the two chisel alignments and a projectile velocity of $V_x = 0.18$ cm/µs. For these cases the explosive initiated. Some asymmetry was seen in the reaction and in the material ejected at the surface of the warhead body.

RUN STATISTICS

The following table lists run statistics for the calculations:

Case	*Dimen-sion*	*Cell Size (cm)*	*Effort (cy/ms)*	*Number of Cells*	*Vx (cm/ms)*	*Computer*	*System*	*Run Time/ Prob. Time (min/ms)*
1	2D	0.025	316	4482	0.16	DX4/100	DOS	27
2	2D	0.025	1109	4482	0.18	DX4/100	DOS	83
3	2D	0.050	137	1170	0.16	DX4/100	DOS	1.8
4	2D	0.050	386	1170	0.18	DX4/100	DOS	5.5
5	3D	0.050	187	25118	0.16	P-Pro/200	Win/NT	11
6	3D	0.050	469	25118	0.18	P-Pro/200	Win/NT	28

The calculation effort, measured as the number of cycles per microsecond of problem time, is nominally inversely proportional to the cell size. Cases 1 and 3 and cases 2 and 4 indicate that the effort increased by respective factors of 2.3 (=316/137) and 2.9 (=1109/386) when the cell size was reduced by a factor of two, somewhat greater than the expected value. Cases 3 and 5 and cases 4 and 6 indicate that the effort is greater for the 3D calculations than for the 2D calculations by respective factors of 1.4 (=187/137) and 1.2 (=469/386).

The ratio of run time to problem time (last column) nominally scales with the inverse cube of the cell size for 2D calculations. Cases 1 and 3 and cases 2 and 4 indicate that the respective exponents are 5.6 [=ln(27)/ln(1.8)] and 2.6 [=ln(83)/ln(5.5)] for this set of calculations.

The ratio [Effort×(Number of Cells):(Run Time/Prob. Time)], the product of the number of cells and the number of cycles, divided by the run time, is a measure of computational efficiency. It averages 85,600 cell·cycles/min for AUTODYN 2D on a DX4/100 computer running under DOS and 423,900 cell·cycles/min for AUTODYN 3D on a Pentium Pro computer running under Windows/NT.

CONCLUSIONS

For determination of the threshold for prompt initiation from side impact of FSP's on large-diameter, steel-bodied warheads, the two-dimensional approach appears adequate. Although there were some differences in the two-dimensional and three-dimensional pressures and reaction timings, they were not great enough to change the computed thresholds for initiation, which were somewhat higher than those obtained in the tests.

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