

An Overview of Analysis and Test Support for the MUNITIONS SURVIVABILITY TECHNOLOGY Program

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Abstract

The MUNITIONS SURVIVABILITY TECHNOLOGY (MST) program was initiated by the Defense Ammunition Logistics Activity to develop a rapidly deployable system of fragment barricades combined with lightweight fire-inhibiting blankets, with guidelines for their use to prevent or reduce propagation of explosions and fire between stacks of Army munitions. In order to ensure the maximum effectiveness of such systems, the U.S. Army Research Laboratory has undertaken a program to elucidate relevant propagation mechanisms, enhance predictive techniques for propagation, and develop data required for the evaluation of the system to be fielded. Available resources include the FRAGPROP model for predicting propagation of detonation and burning reactions between ammunition stacks, the FRAGGEN model for predicting fragmentation of items that are not characterized in arena tests, existing data on gun propellant and rocket motor vulnerability to fragment attack, analyses and test procedures developed in conjunction with the Navy's HIGH-PERFORMANCE MAGAZINE program, and data from hazard classification tests. The MST program is divided into four broad areas: (1) fragment propagation, (2) crushing propagation, (3) fire propagation, and (4) ammunition site design criteria. Although much of this work is still in progress, considerable success has been achieved.

Background

When ammunition is stored in the open, as in contingency operations or when awaiting transportation (e.g., in ports), it is vulnerable to hostile attack or accidental stimuli that may produce fires, violent explosions, propagation between stacks, and consequent large-scale losses. Mechanisms of reaction propagation vary widely depending on the accident scenario and the munitions involved. An informal review of ammunition accident history (Starkenberg, Benjamin, and Frey 1996) revealed that the most common mechanism of propagation of reaction between ammunition stacks involves ignition of fires by fragments, debris, or firebrands from the source explosion and subsequent violent reaction of munitions in those fires. Prompt propagation via primary fragments also remains important.

The MUNITIONS SURVIVABILITY TECHNOLOGY (MST) program was initiated by the Defense Ammunition Logistics Activity. Its objective is to develop a rapidly deployable system of fragment barricades combined with lightweight fire-inhibiting blankets, with guidelines for their use to prevent or reduce propagation of explosions and fire between stacks of Army munitions. In order to ensure the maximum effectiveness of such systems, the U.S. Army Research Laboratory has undertaken a

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program to elucidate relevant propagation mechanisms, enhance predictive techniques for propagation, and develop data required for the evaluation of the system to be fielded.

Issues

A number of technical issues required resolution. Models to predict prompt propagation of detonation between stacks via fragmentation have been developed, but they required validation and, possibly, improvement. Fragment barricades must withstand successive explosions associated with long-term cookoff of ammunition in fires. Further, barricades may promote propagation by crushing nearby acceptor stacks. The nature of burning debris ejected from an ammunition fire and the way in which it is distributed is not well understood, and the response of ammunition stacks to burning debris has not been determined. Blankets may intensify fires if they are penetrated by burning debris, which ignites the stacks they protect. Thus, they must provide at least some level of ballistic protection.

Resources

Available resources include the FRAGPROP model (Starkenber, Benjamin, and Frey 1996) for predicting propagation of detonation and burning reactions between ammunition stacks, the FRAGGEN model (Starkenber, Benjamin, and Frey 1996) for predicting fragmentation of items which are not characterized in arena tests, existing data on gun propellant and rocket motor vulnerability to fragment attack (Collis, Forster, and McLain 1972, Gilman ca.1978), analyses and test procedures developed in conjunction with the Navy's HIGH-PERFORMANCE MAGAZINE program (Tancreto, Swisdak, and Malavar 1994), and data from hazard classification tests.

FRAGPROP (Starkenber, Benjamin, and Frey 1996) is based on an earlier computer program called FRAGHAZ (McClesky 1988) that was developed to predict the hazard to a human target due to fragmentation from an exploding ammunition stack. FRAGPROP is designed to predict detonation and burning propagation probabilities between two ammunition stacks, as functions of the distance between them. The donor stack description and Monte-Carlo analysis of the trajectories of the fragments characterizing that stack are nearly identical to those used in FRAGHAZ. Effects of penetrating external containers and user-specified limits on fragment mass and initial elevation angle were added. FRAGPROP includes descriptions of the vulnerable components (warheads and rocket motors) of munitions in the acceptor stack and applies detonation initiation and burning ignition criteria whenever a fragment impacts the target stack. The effects of penetrating an external container are included here also. The vulnerability of a weapon component to initiation of detonation by fragment impact is described by the Jacobs-Roslund formula for critical impact velocity (Liddiard and Roslund 1993). The model for ignition of burning makes use of a threshold corresponding to a specified residual velocity computed using the THOR equations. In general, the residual velocity appropriate for use with a specific ammunition item is not known and a residual velocity of zero has been used as a worst case in prior analyses. The burning produced may be either mild or violent. The violence of the burning response is not predicted by FRAGPROP.

FRAGGEN (Starkenbergh, Benjamin, and Frey 1996) is a simple model for estimating the fragment output from any item that can be represented as a cylindrical charge with a fragmenting case. It does not account for fragment interactions with neighboring items. The distribution of fragment masses is given as a function of the average fragment mass by the Mott equation (Victor 1994). The average fragment mass may be related to the properties of the charge and casing, and the total fragment mass is equated to the casing mass. The velocity of the fragments is determined using the Gurney analysis for the assumed configuration and is the same for all fragments.

An early study of the vulnerability of cased gun propellant to fragment attack was conducted by the New Mexico Institute of Mining and Technology (Collis, Forster, and McLain 1972) for the U.S. Army Ballistic Research Laboratories. This study includes tests in which cylindrical steel fragments with known characteristics were fired at various velocities at simulated U.S. 40-mm (brass casings) and 105-mm (brass and steel casings) artillery ammunition containing either M1 (single-based), M2 (double-based), or M30 (triple-based) granular propellant. Some tests were also conducted on U.S. 5-in and Soviet 122-mm rocket motors. The parameters studied include fragment velocity, mass, temperature, and obliquity, as well as case material, and propellant chemistry and geometry. Because of the instability of the fragments in flight and poor control of the impact obliquity (even though the impact faces of the cartridge cases were flattened), large regions of mixed results were obtained in this study and V_{50} values were reported. The threshold residual velocity corresponding to the V_{50} values vary between approximately 450 and 1,000 m/s. Results of an Air Force study of the mechanisms by which impacting fragments ignite cased granular gun propellants were reported by Gilman (ca. 1978). In order to facilitate fragment firing and accurately control impact conditions, fragment-simulating projectiles (spheres, cubes, and, occasionally, cylinders) were fired against flat-plate-faced replica cartridge-case targets containing M1 (single-based) or M26 (double-based) propellant. In each series of firings, the impact velocity of the fragments was varied in order to accurately determine a threshold value. This approach greatly reduces or eliminates regions of mixed results so that V_{50} values need not be used. In this study, the residual velocities varied between 200 and 800 m/s. These values are lower than those determined in the BRL study. The highest values found in the Air Force study were generally associated with special target cover materials that are not representative of munitions (e.g., epoxyboard). Analysis of over 4,000 firings indicates that energy transfer from casing material heated by thermoplastic shear during the perforation process is the dominant mechanism causing propellant ignition. It is clear from a study of these data that residual velocity is not a sufficient criterion for predicting ignition of gun and rocket propellants. However, it is useful because casing perforation is prerequisite to ignition.

In conjunction with the development of the Navy's HIGH-PERFORMANCE MAGAZINE, Tancreto, Swisdak, and Malavar (1994) identified criteria for the propagation of reaction that is facilitated by intervening barricades in ammunition storage arrangements. The most important propagation mechanisms they identified are direct shock loading and crushing of the casing caused by impact of the barricade on acceptor ammunition. Their criterion for shock initiation is based on the concept of critical energy fluence. While this is not a directly measurable quantity, it can be computed for a specific arrangement and the presence or absence of propagation can be verified in experiments. The crushing-propagation criterion is related to the total deformation experienced by the acceptor, usually expressed as the ratio of the net change in a munition's diameter to its original diameter.

Program Design

The Army ammunition inventory is vast, and the resources of the MST program are limited, precluding in-depth exploration of all technical issues. The tasks to be performed had to be carefully considered in light of prior work. Representative ammunition items were selected from the Army inventory, subject to availability. The emphasis of the program was on developing models for extending results to untested items. The MST program was divided into four broad areas: (1) fragment propagation, (2) crushing propagation, (3) fire propagation, and (4) ammunition site design criteria. Much of this work is still in progress. It will be completed during 1999.

Fragment Propagation

In order to benchmark predictions from FRAGPROP, propagation tests using 155-mm M107 projectiles were conducted. The predicted frequencies of detonation and burning propagation are somewhat greater than those observed in the tests. While the results do not provide sufficient data to validate the FRAGPROP predictions with a high level of confidence, they indicate that they are reasonable representations of the actual responses of these munitions. These tests and their results are detailed in another paper submitted to this seminar (Hillstrom and Starkenberg 1998).

In addition, efforts were made to analyze existing data to establish models for ignition of burning reactions in energetic components caused by fragment impact. Analysis with FRAGPROP has shown that using a residual velocity of zero as a worst case does not inordinately increase the distance associated with a given propagation probability.

In order to evaluate the effectiveness of barricades against multiple fragments and to develop predictive models, sand and water penetration experiments are being conducted. Preliminary results with water indicate limited effectiveness at a two-foot thickness.

In order to benchmark predictions of fragmentation from a missile warhead generated by FRAGGEN, an arena test on a single Hellfire missile was performed. Aluminum fragments in addition to those produced by the warhead were recovered and analyzed. The analysis indicates that the predicted distribution is accurate for the smallest fragments, which comprise most of the total number. Measured fragment velocities were much lower than the Gurney predictions employed by FRAGGEN, and the fragments failed to ignite any of the witness propellant canisters. Because the configuration used in the single Hellfire test does not represent the actual storage arrangement, and in order to determine the effects of multiple simultaneous detonations and the presence of external packaging, an arena test on two Hellfire missiles in their containers was conducted. Comparison of the fragment mass distributions produced in the two tests indicates depopulation of the smaller fragment sizes in the second test. This renders the FRAGGEN predictions inaccurate. The fragments produced in this test started burning reactions in the witness propellant canisters. A final arena test with two 155-mm M864 ICM projectiles containing submunitions, conducted in an attempt to develop fragmentation data for this configuration, was not successful. These tests and their results are detailed in another paper submitted to this seminar (Hillstrom and Starkenberg 1998a).

Crushing Propagation

In order to assess crushing propagation, it is necessary to determine the motion that may be imparted to candidate barricades by the explosion of a representative ammunition stack, and then to determine the resultant loading on potential acceptors. Computations of barricade response to blast loading have been conducted using the hydrocode CTH. This is the subject of another paper submitted to this seminar (Lottero 1998). This paper documents the two-dimensional numerical simulation of the detonation of a simplified donor stack in a temporary storage area and the subsequent effects on an adjacent water barricade and simplified acceptor stack. The donor stack is represented as an uncased, condensed, high-explosive charge with a rectangular cross section. The water barricade has a trapezoidal cross section, and the acceptor stack is a solid rectangle. Computed parameters include the loading on and within and the motion of the barricade. A separate computation was then run to simulate the water barricade interacting with the acceptor stack. Subsequently, computations to address acceptor critical energy fluence and deformation will be made and the criteria developed by Tancreto, Swisdak, and Malavar (1994) will be applied.

Fire Propagation

A survey of information pertinent to the ignition of wood packaging by hot fragments was undertaken by Vande Kieft and Hillstrom (1997). They concluded that fragments from exploding ordnance frequently possess sufficient energy to ignite wood and support continued combustion.

A series of tests was conducted in an attempt to characterize the material ejected from burning ammunition stacks that represents a hazard to other stacks nearby. These tests are the subject of two other papers in this seminar (Hillstrom and Starkenberg 1998b; Pergantis and Mulkern 1998). Six representative ammunition items were chosen to act as firebrand donors. They are 25-mm M791 APFSDS-T projectiles, AGM-114A Hellfire missiles, 105-mm M1 HE projectiles, 155-mm M549A1 HERA projectiles, 155-mm M864 ICM projectiles, and 105-mm M416 WP-T projectiles. The items to be tested were attached to a steel burn stand over a propane burner. The burner was ignited remotely, and the gas flow was stopped after 30 minutes (earlier if the donor ordnance was expended). Distributed firebrands were "witnessed" by matrixes of panels arranged along four radials extending to 200 feet from the burner. The panels consisted of either plywood sheets or sheet-metal trays filled with layers of JA-2 gun propellant. In addition, some of the debris fields were mapped after the tests, and some of the tests were covered by infrared (IR) videography.

The firebrands and debris ejected in these tests varied widely. Their masses ranged from microscopic up to 46 kg. Some firebrands resulting from detonations or violent explosions were launched with high kinetic energy, while others were launched more softly. The materials that were ejected included burning propellant, burning wood, molten aluminum, and unexploded submunitions. Burning of the plywood and propellant witness panels indicate that many of these ejecta could easily ignite nearby ammunition, although the cause of specific panel ignitions was often unclear. Burning propellant grains seemed to have the greatest incendivity. Burning wood also started fires easily and molten aluminum splatters were suspected to have started several propellant burns. These materials

tend to cool during flight and did not start fires in the propellant witness panels far from the burner. Secondary explosions of the M864 submunitions and one M549 projectile were observed downrange.

Site Design Criteria

The development of ammunition storage site design criteria represents the culmination of the program, in which requirements for prevention of fragment penetration of barricades, acceptor crushing, and ignition of fires in acceptors are combined to analyze and design a test site. Two large-scale validation tests, one with a detonated donor stack and one with an ignited donor stack, are planned. The final design of these tests will depend on the results of the current studies.

Conclusion

Although much of this work remains to be completed, analysis and test support for the MST program has made considerable progress and promises to provide the information essential to success of the deployed system.

References

- Collis, D. L., J. J. Forster, and J. P. McLain. "Vulnerability of Propellant-Filled Munitions to Impact by Steel Fragments." Contract Report No. 65, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, MD, March 1972.
- Gilman, R. D. "Cased Granular Propellant Ignition by Fragment Impact." Source unknown, ca. 1978.
- Hillstrom, W. H., and J. Starkenberg. "Benchmark Tests for Fragmentation and Propagation Models." 28th Department of Defense Explosives Safety Seminar, Orlando, FL, August 1998a.
- Hillstrom, W. H., and J. Starkenberg. "Propagation of Firebrands from Burning Ammunition Stacks." 28th Department of Defense Explosives Safety Seminar, Orlando, FL, August 1998b.
- Liddiard, T. P., and L. A. Roslund. "Projectile/Fragment Impact Sensitivity of Explosives." NSWC-TR-89-184, Naval Surface Warfare Center, Silver Spring, MD, June 1993.
- Lottero, R. E. "Numerical Modeling of the Responses of a Water Barricade and an Acceptor Stack to the Detonation of a Donor Munitions Stack." 28th Department of Defense Explosives Safety Seminar, Orlando, FL, August 1998.
- McClesky, F. "Quantity-Distance Fragment Hazard Computer Program (FRAGHAZ)." NSWC-TR-87-59, Naval Surface Warfare Center, Silver Spring, MD, February 1988.

Pergantis, C. G., and T. J. Mulkern II. "A Novel Real-Time Technique to Evaluate Fragments From Exploding Munitions." 28th Department of Defense Explosives Safety Seminar, Orlando, FL, August 1998.

Starkenbergh, J., K. J. Benjamin, and R. B. Frey. "Predicting Fragmentation Propagation Probabilities for Ammunition Stacks." ARL-TR-949, U.S. Army Research Laboratory, January 1996 (see also 27th Department of Defense Explosives Safety Seminar, Las Vegas, NV, August 1996.)

Tancreto, J. E., M. Swisdak and J. Malavar. "A High Performance Magazine Acceptor Threshold Criteria." 26th Department of Defense Explosives Safety Seminar, Miami, FL, August 1994.

Vande Kieft, L. J. and W. W. Hillstrom. "Ignitability of Wood from Fragment Attack." ARL-MR-381, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, December 1997.

Victor, A. C. "Prediction/Analysis of Munition Reactions for Insensitive Munitions Threat Hazard Assessment." *Proceedings of the Insensitive Munition Technology Symposium*, Williamsburg, VA, June 1994.