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AN EVALUATION OF MUZZLE FLASH PREDICTION MODELS

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
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Secondary muzzle flash results from the reignition of a mixture of fuel-rich exhaust gases and entrained air. This combustion process releases energy in the form of light, the objectionable "flash," and also noise, in the form of secondary blast which adds to the primary blast of the weapon. Three different techniques for predicting secondary flash occurrence have been tested in simulated artillery and mortar firing situations. The predictions of the techniques are compared, and, where observational data exist, the predictions are compared to them. The Standard Plume Flow (SPF) code, for

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) rockets, has recently become available. While we found that it is not yet ready for application to guns, it has many appealing features.

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I. INTRODUCTION

Three kinds of factors affect secondary muzzle flash. The first, chemical factors, include the presence of flash suppressant in the charge, the flame temperature of the propellant, and the chemical composition of the propellant. Physical factors include the exit condition of the propellant gas (temperature, pressure, and velocity) and the location and strength of shocks in the muzzle flow. Mechanical factors which affect secondary muzzle flash include both the intentional effects of flash hiders and the unintentional effects of muzzle brakes.

Secondary muzzle flash has always been viewed as undesirable because it identifies the location of the gun and because it reduces the night vision of the gun crew. More recently, however, it has been realized that the combustion which leads to optical energy release (IR, visible, and/or UV) also leads to acoustic energy release - noise. This is important because many weapons already operate near their noise limit. The suppression of secondary flash provides a means of reducing the blast noise of the weapon.

Historically, flash has been suppressed (when it was possible) using mechanical "flash hiders" (slotted, cone shaped, etc.) or chemical salts (usually a potassium or sodium compound). The former method is effective for small arms, but considered too cumbersome for large caliber weapons. The latter works sometimes, but yields an accompanying smoke cloud, which can be quite detrimental in some situations. The use of propellants with lower flame temperatures has worked to reduce flash when the chamber of the weapon has been large enough for the increased charge weight required to maintain the muzzle velocity.

Several techniques have been developed for predicting whether or not a gun will flash.

(1) Carfagno developed a technique of predicting the temperature of the mixture of muzzle gases and entrained air and then comparing it to experimentally determined ignition limits to predict flash/no-flash conditions.[1] May and Einstein improved on Carfagno's procedure.[2]

(2) Yousefian developed the muzzle exhaust flow field (MEFF) flash prediction model.[3] MEFF incorporates detailed chemistry, and ignition is indicated by a sharp increase in the mixture temperature.

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1. S. P. Carfagno, "Handbook on Gun Flash," Franklin Institute Report, Contract No. DA-36-034-514-ORD-78RD, November 1961 (AD 327 051).

2. I. W. May and S. I. Einstein, "Prediction of Gun Muzzle Flash," ARBRL-TR-02229, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, March 1980 (AD A083 888).

3. V. Yousefian, "Muzzle Flash Onset," ARI-RR-236, Aerodyne Research, Inc., Billerica, MA, Nov 80. Also available as ARBRL-CR-00477, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, February 1982 (AD B063 573L).

(3) Schmidt has published an improvement to the Carfagno/May/Einstein procedure.[4] He improved the description of the flow from the muzzle and added elements of unsteady flash analysis.

Finally, the Standard Plume Flow (SPF) model has been released to the rocket community.[5] For cases for which the exhaust-gas/ambient-air pressure ratio is fairly low, SPF can describe the flow expansion, the formation of the shocks, and the detailed chemistry taking place in the flow. Even though SPF was not originally intended to be used for describing gun muzzle flow, and it is not yet a "flash prediction technique," we tested it for a case it could address.

II. FLASH PREDICTION TECHNIQUES

In this section, we examine the three flash prediction techniques introduced above.

A. Carfagno/May/Einstein (CME)

The first technique used in this report was that of Carfagno,[1] as corrected and improved by May and Einstein.[2] This procedure assumes that the muzzle gases expand to atmospheric conditions, are heated by passage through the shock disk, and are then mixed with ambient air. It calculates the temperature of the muzzle gas/air mixture as a function of the fraction of entrained air in the mass of the mixture. When this temperature exceeds experimentally determined ignition limits, flash is likely to occur. Table I is a guide for predicting whether reignition of the mixture will lead to secondary flash in artillery firings;[6] it assumes that the muzzle gases contain over 40% combustibles. After a CME calculation is performed, and the peak predicted muzzle gas/air mixture temperature is established, one looks in Table I at the row corresponding to the given percentage of suppressant and notes in which column the calculated temperature best fits.

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4. E. M. Schmidt, "Secondary Combustion in Gun Exhaust Flows," ARBRL-TR-02373, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, October 1981 (AD A107 312).

5. S. M. Dash and H. S. Pergament, "The JANNAF Standard Plume Flowfield Model (SPF)," MICOM Technical Report RD-CR-82-9, April 1981. S. M. Dash and H. S. Pergament, "JANNAF Standard Plume Flowfield Model (SPF), Program Users Manual for Interim Version (SPF-1)," MICOM Special Report RD-81-4, July 1981.

6. G. E. Keller, "Secondary Muzzle Flash and Blast of the British 81-mm, L16A2 Mortar," ARBRL-MR-03117, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1981 (AD A104 324).

TABLE 1. FLASH PREDICTION FOR ARTILLERY WEAPONS

Flash Suppressant (%)	Mixture Temperatures (K)		
	Weapon Regularly Flashes	Weapon Marginally Flashes	Weapon Never Flashes
0	900	800	700
1	1125	1025	925
2	1225	1125	1025
2.7	1275	1175	1075

B. Muzzle Exhaust Flow Field (MEFF)

The version of the Muzzle Exhaust Flow Field (MEFF) model that we used is very close to that documented in ARI-RR-236.[3] The application of MEFF includes the use of the LAPP code,[7] which uses detailed reaction chemistry to predict the occurrence of flash. Thirteen (13) atomic and molecular species are considered, including KO_2 and HO_2. These are linked by the "extended kinetics" reaction set of 25 reactions.[3] The one significant change in MEFF that has taken place after the publication of Reference 4 is a change in the diameter of the Mach disk. After the work of Schmidt,[4] and at the suggestion of V. Yousefian,[8] who developed MEFF, we have increased the diameter of the Mach disk. Thus the multiplier in the equation which calculates the fraction of the propellant gases which pass through the Mach disk is 0.96 instead of the original 0.52 in MEFF. We have compared the results of our calculations with those of V. Yousefian to assure ourselves that our results are identical to his.

C. Schmidt

Schmidt has published a report[4] which summarizes existing flash models and makes significant improvements to the CME method, incorporating some of the same flow description as MEFF. He added a relaxation to sonic flow for the gases out of the gun muzzle after the projectile has emerged. The flow is processed through both lateral shocks and the Mach disk, as in MEFF. The muzzle gas and air are assumed to mix instantaneously, as in CME. Finally, the resulting muzzle gas/air temperatures are compared to ignition criteria, such as are summarized in Table I. Beyond that, however, Schmidt made two distinctive additions. He suggested a procedure for approximating the effect

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7. R. R. Mikatarian, C. J. Kau, and H. S. Pergament, "A Fast Computer Program for Nonequilibrium Rocket Plume Predictions," AFRPL-TR-72-94, Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, CA, August 1972.

8. V. Yousefian, personal communication.

of a muzzle brake and showed that, for an artillery case, a brake could transform a marginal flasher into one that flashed every time. Thus, his model results agree with observations.[9] Further, he used data from models and observations to approximate the effect that unsteady components of the muzzle flow would have on the ignition of secondary flash. In this report, we consider only the steady-state portion of the Schmidt model and note that brakes can exacerbate a flash problem.

III. ARTILLERY COMPARISONS

To compare the flash prediction techniques, we have made flash predictions for several propellants in artillery situations. We standardized on an interior ballistic calculation for a 155-mm howitzer, using the M203 charge (less its added salt bag) to fire an M483A1 projectile. For more details, see Appendix A. Grain dimensions and charge weights for each subsequent charge were chosen to approximate the peak pressure and match the muzzle velocity (808 m/sec) of our "standard" calculation. It should be noted at the outset that the two cooler propellants have significantly less impetus, so that it would take larger charges to achieve the same ballistics, with the result that it might prove difficult or even impossible to load the calculated amounts into the chambers of available weapons. Nonetheless, the results are interesting.

A. Propellants

The propellants that were used for the artillery simulations are described in Table II. For convenience, they are each assigned a short name for future reference. Adiabatic flame temperatures were computed with BLAKE;[10] see Appendix A for more details.

B. Results

Table III shows the results of CME, MEFF, and Schmidt calculations for the six propellants listed above. For each calculation, there is a statement about whether the weapon firing the "M203" charge with that propellant would be expected to flash. Below that statement, for CME and Schmidt calculations, is listed the peak mixture temperature that resulted from the flow, mixing, and shocks; one can compare these temperatures with those in Table I to find that the closest column was chosen. For the MEFF calculations, each statement has below it the distance from the muzzle (in meters) that the mixture temperature first exceeded 1200 K, so that ignition was assured. (If one examines a series of MEFF calculations for increasing amounts of suppressant, one finds that ignition is predicted to take place farther and farther from the muzzle, until, at last, ignition does not occur. Or, expressed from a

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9. E. M. Schmidt, "Gun Muzzle Flash and Associated Pressure Disturbances," AIAA-81-1109, 23-25 June 1981, Palo Alto, CA.

10. E. Freedman, "BLAKE - A Thermodynamic Code Based on TIGER: User's Guide and Manual," ARBRL-TR-02411, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1982 (AD A121 259).

TABLE 2. PROPELLANTS USED FOR ARTILLERY STUDIES

Name	Description	Adiabatic Flame Temperature
M30(WO)	Nominal M30A1 propellant, from which the suppressant has been removed.	3035 K
M30A1	Nominal M30A1 propellant, which contains 1% K_2SO_4 suppressant.	3003 K
M30(W2)	Nominal M30A1 propellant, but with 2% K_2SO_4 suppressant.	2971 K
M30A2	Nominal M30A2 propellant, which includes 2.7% KNO_3 suppressant.	3045 K
M30A2M	Nominal M30A2 propellant, but the KNO_3 suppressant has been replaced with K_2SO_4 suppressant.	2951 K
KRATON	RDX with Kraton G1652 binder.[11] This LOVA candidate was chosen from among all the LOVA candidates based on its chemical composition; its combustion led to no significant molecular species that were not on the list of the 13 species that MEFF treats.	2244 K
PU/HMX	HMX with L-35 (polyether) binder.[11] Chosen for the same reason as KRATON above.	2434 K

different perspective, MEFF predicts that the farther from the muzzle the mixture ignites, the less likely the weapon is to flash.)

C. Comparisons

The agreement between the predictions is very good. CME and Schmidt agree very well in all cases, with Schmidt consistently predicting a somewhat lower mixture temperature, and both agree quite well with MEFF except for the cases of M30(W2) and M30A2. In those cases, MEFF predicts ignition occurring at great distances from the gun muzzle, and the two other codes agree that the weapon should never flash. With 2.7% suppressant, one might have guessed that M30A2 would never flash, but note that its adiabatic flame temperature is significantly higher than M30A1 or M30(W2). Its performance led to the fifth case in Table III, for M30A2M, for which the suppressant was changed. A lower adiabatic flame temperature resulted (see Table II), and all the codes agreed

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11. R. W. Deas, G. E. Keller, and J. J. Rocchio, "The Interior Ballistic Performance of Low Vulnerability Ammunition (LOVA)," CPIA Publication 340, Proceedings of the 1981 JANNAF Propulsion Meeting, Vol. III, pp 437-477, May 1981.

TABLE 3. FLASH PREDICTIONS FOR ARTILLERY FIRINGS

Propellant	CME Prediction	MEFF Prediction	Schmidt Prediction
M30(WO)	Regularly (1092 K)	Promptly (5)	Regularly (1066 K)
M30A1	Regularly (1083 K)	Yes (15)	Marginally (1057 K)
M30(W2)	Never (1070 K)	Yes (32)	Never (1045 K)
M30A2	Never (1102 K)	Yes (30)	Never (1074 K)
M30A2M	Never (1063 K)	No	Never (1037 K)
M30A2M(hot)		Yes (30)	
KRATON	Marginally (800 K)	No	Marginally (799 K)
PU	Marginally (831 K)	No	Marginally (835 K)

that there should be no flash. The sixth case in Table III is for "M30A2M(hot)," where "hot" refers to the temperature of the gas exiting the gun, not the condition of the propellant prior to firing. It was run to see whether it was the change in suppressant (from KNO_3 to K_2SO_4) chemistry or the change in the muzzle gas exit conditions (reflecting the decrease in the adiabatic flame temperature) for M30A2M which led to the no-flash condition. For this case, the mean gas temperature (of the propellant gases at the time of shot ejection) was assumed to be equal to that for M30A2. The result of the calculation was that M30A2M(hot) flashed as readily as M30A2, suggesting (but certainly not proving) that the adiabatic flame temperature reduction achieved by switching suppressants, which led to a lower muzzle gas temperature, caused the no-flash results for M30A2M. The codes agreed that KRATON or PU used in artillery charges (provided the problem of chamber volume limitation could be overcome) should be only marginally flashy, at worst.

IV. MORTAR COMPARISONS

Here we have made flash predictions for several propellants used in an 81-mm mortar firing situation. We standardized on the well-studied British L16A2, 81-mm mortar, whose standard propellant was very close to M10 without the suppressant. Charge weights were varied to give matching top-zone muzzle velocities, 944 m/s. For more details, see Appendix B.

A. Propellants

The propellants that were used for the mortar simulations are described in Table IV. For convenience, they are each assigned a short name for future reference. Again, more details are given in Appendix B.

TABLE 4. PROPELLANTS USED FOR MORTAR STUDIES

Name	Description	Adiabatic Flame Temperature
M10(WO)	Nominal M10 propellant from which the suppressant has been removed.	3050 K
M10	Nominal M10 propellant, which has approximately 1% K2SO4 suppressant	3018 K
M10(W2)	Nominal M10 propellant, but with 2% suppressant.	2983 K

B. Results

Table V shows the results of CME, MEFF, and Schmidt calculations for the three propellants listed above. As before, for each situation there is a statement about whether the system would be expected to flash, and below that either (for CME or Schmidt) the peak mixture temperature of the muzzle gas-air mixture or (for MEFF) the distance in meters from the muzzle at which the calculated mixture temperature first exceeded 1200 K, so that ignition was assured.

TABLE 5. FLASH PREDICTIONS FOR MORTARS

Propellant	CME Prediction	MEFF Prediction	Schmidt Prediction	Observation
M10(WO)	Regularly (1210 K)	Yes (0.5)	Regularly (1186 K)	Yes
M10	Regularly (1198 K)	Yes (2.3)	Regularly (1175 K)	No
M10(W2)	Regularly (1185 K)	No	Marginally (1162 K)	No

C. Comparisons

Again, the agreement between the predictions of CME and Schmidt is very good, but this time the agreement with the predictions of MEFF is not so good. Further, the observational data indicate[12] that with as little as 1%

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12. C. Wright, presented at the Improved 81-mm Mortar Review, Dover, N.J., May 1980.

suppressant, the mortar never flashed, so that by 2%, there should be no doubt. I previously proposed a second, shifted table of ignition criteria for mortars,[6] which was adjusted so that the CME technique gave the right answers. That is not a very satisfying approach if one is doing model comparisons, though it works if one is trying to build a mortar that does not flash. In this case, one should perhaps just note that while MEFF does a better job of predicting flash for mortars than either CME or Schmidt, it is not perfect.

V. STANDARD PLUME FLOW MODEL

The Standard Plume Flow (SPF) model from the rocket community[5] has been implemented at the Ballistic Research Laboratory (BRL), and we have reproduced the test cases to be sure that it is functioning correctly. SPF-1, the first version of the code, and the version that was used for this work, starts with the conditions at the exit plane of a rocket nozzle and calculates the size and locations of the Mach disk and the barrel shocks. It overlays the inviscid calculation with a viscous one, in which one can specify the mixing rules to be followed at the boundaries. The BOAT code, a part of SPF, then does a detailed time-stepping calculation, using detailed chemistry, of the temperature, pressure, density, etc., in the mixed region. Secondary burning, or afterburning, is clearly visible as a marked temperature increase, in the same fashion as MEFF.

However, SPF is a rocket flow code; it was not written to be a gun flash prediction code. SPF has been especially modified for the BRL so that it can handle a gun tube with an attached nozzle, the nozzle of any arbitrary (axisymmetric) shape. The most suitable standard chemistry set of the several offered by the SPF package handles only 9 species and 10 equations, many less than MEFF has included at this time. It has been easy, however, to add both the HO_2 molecule and appropriate reactions to the basic set available, so that the chemistry set is the same as the one in MEFF, except that it lacks suppressant chemistry. The first calculations with SPF predict that the standard British L16A2 81-mm Mortar with two-caliber muzzle cone would flash, whereas in practice, the cone eliminates the secondary flash completely.[12]

At this writing, SPF cannot handle a calculation starting from a bare gun muzzle when the projectile exits subsonically because it cannot start with a flow of Mach Number exactly one, as is quickly set up behind the exiting projectile. Modifications are being discussed to permit such cases to be handled. This and other present limitations imply that the time has not yet come to use SPF as a working flash prediction code. However, with its many advanced features, SPF holds promise for the future.

VI. CONCLUSIONS

For the time, then, one should not use SPF for a gun muzzle flash prediction study. Further, the steady portion of the Schmidt model has better physics than CME; one should use it rather than CME. Facing a study of flash prediction for a new system, then, which is better, MEFF or Schmidt? It obviously depends on what is to be studied. If the study is of a wholly new system, with characteristics far from those for which CME or Schmidt were developed, MEFF, as the above mortar work shows, is the choice, even though its predictions are not always correct. If one is studying a new suppressant, MEFF is the only choice. If one wants to vary physical factors for a fairly well-known system - for example, if one wants to vary propellant compositions for a 155-mm howitzer and note the effect of the differing adiabatic flame temperatures - Schmidt will do just fine, and it uses much less computer time. Future exploitation of the quasi-time-dependent aspects of the Schmidt model will increase opportunities for its use.

One should not conclude from this study that the physics and chemistry of gun muzzle exhaust flows are well "modeled." None of the authors of the several codes makes such a claim. The models we have examined are all compromises in one way or the other, so that each has limited applicability. The goal of this work goes beyond just getting the "right answers" for the flash of a system, however. For that, a much simpler model with many adjustable parameters would suffice. Instead, we strive for models which give the right answers for the right physical and chemical reasons, so that, someday, muzzle flash can be controlled.

ACKNOWLEDGMENTS

Many different people have assisted in research documented in this report or in this description thereof. I wish to thank E. Schmidt, V. Yousefian, H. Pergament, R. Deas, W. Anderson, W. Lippincott, E. Freedman, I. May, A. Horst, and E. Wright for their many contributions.

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3. V. Yousefian, "Muzzle Flash Onset," ARI-RR-236, Aerodyne Research, Inc., Billerica, MA, Nov 80. Also available as ARBRL-CR-00477, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, February 1982 (AD B063 573L).

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7. R. R. Mikatarian, C. J. Kau, and H. S. Pergament, "A Fast Computer Program for Nonequilibrium Rocket Plume Predictions," AFRPL-TR-72-94, Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, CA, August 1972.

8. V. Yousefian, personal communication.

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11. R. W. Deas, G. E. Keller, and J. J. Rocchio, "The Interior Ballistic Performance of Low Vulnerability Ammunition (LOVA)," CPIA Publication 340, Proceedings of the 1981 JANNAF Propulsion Meeting, Vol. III, pp 437-477, May 1981.

12. C. Wright, presented at the Improved 81-mm Mortar Review, Dover, N.J., May 1980.

A-1. P. G. Baer and J. M. Frankle, "The Simulation of Interior Ballistic Performance of Guns by Digital Computer Program," BRL Report No. 1183, U.S. Army Aberdeen Research and Development Center, Ballistic Research Laboratories, Aberdeen Proving Ground, MD, December 1962 (AD 299 980).

APPENDIX A

ARTILLERY SIMULATION DETAILS

To exercise any of the flash prediction techniques studied in this report, one first performs a thermodynamics calculation, then an interior ballistic simulation, and then runs the flash prediction code itself.

For the artillery studies, we started out with BLAKE, Version 205.1.[10] The basic M30A1 propellant was assumed to have the following ingredients (with percentages by weight): nitrocellulose (12.6% N), 27.9; nitroglycerin, 22.42; nitroguanidine, 46.84; ethyl centralite, 1.49; K_2SO_4, 1.0; ethyl alcohol, 0.25; and carbon (graphite), 0.1. It was assumed that there was NOT a "salt bag" tied to the front of the charge. Liquids and solids were rejected as equilibrium products, since they are unlikely to form in significant amounts at the temperatures and pressures being considered. (In fact, we did the calculation for both cases, first suppressing and then not suppressing solids and liquids, and we found that there was a negligible difference in the interior ballistic calculational results which followed.) The loading density for all calculations was assumed to be 0.2 g/cc. The calculations yielded an adiabatic flame temperature of 3003 K, an impetus of 1065.5 J/g, a molecular weight for the gas of 23.432, a co-volume of 1.041 cc/g, an interior ballistic gamma of 1.2412, and a specific heat at constant pressure (frozen) of 44.2 J/mol-K.

The interior ballistic code used was that of Baer and Frankle.[A-1] The 155-mm howitzer was assumed to have a chamber volume of 0.01966 m^3 (1200 $in.^3$), and the 46.36-kg (102.2-lb) M483A1 projectile was assumed to have a travel of 5.08 m (200 in.). The best available bore resistance and burning rates were used. It was assumed that 11.86 kg (26.15 lb) of M30A1, 0.227 kg (0.5 lb) of NC tube, and 0.143 kg (0.315 lb) of black powder were used. The standard calculation resulted in a muzzle velocity of 808 m/s (2650 ft/sec), a maximum breech pressure of 329.4 MPa (47.77 kpsi), a base pressure at shot ejection of 71.3 Mpa (10.34 kpsi), and a muzzle gas temperature at shot ejection of 1733 K.

At this point, the CME and Schmidt codes were run and the results compared to Table I to predict flash. The first part of the MEFF code, which does the flow field calculations, was then run. A thermodynamics code was used again to obtain product distributions after predicted shock heating; we used BLAKE, again rejecting any solid or liquid-phase equilibrium products. We did this because it is currently assumed that flash suppression takes place because of gas phase chemistry, and we did not want any of the suppressant tied up in a solid or liquid phase product. Finally, the LAPP portion of the MEFF procedure was run, which resulted in the flash/no-flash predictions.

A-1. P. G. Baer and J. M. Frankle, "The Simulation of Interior Ballistic Performance of Guns by Digital Computer Program," BRL Report No. 1183, U.S. Army Aberdeen Research and Development Center, Ballistic Research Laboratories, Aberdeen Proving Ground, MD, December 1962 (AD 299 980).

APPENDIX B

MORTAR SIMULATION DETAILS

The starting point for the mortar studies was nominal M10 propellant, which has the following ingredients (with percentages by weight): nitrocellulose (13.15% N), 96.04; diphenylamine, 0.980; K_2SO_4, 0.980; H_2O, 0.5; and ethyl alcohol, 1.5. As before, liquid and solid products were rejected. The loading density for all mortar calculations was assumed to be 0.065 g/cc, for that yielded a pressure about equal to the maximum pressure expected in the mortar simulation. The BLAKE calculations yielded an adiabatic flame temperature of 3018 K, an impetus of 1022.3 J/g, a molecular weight for the gas of 24.544, a co-volume of 1.063 cc/g, an interior ballistic gamma of 1.2321, and specific heat at constant pressure (frozen) of 44.48 J/mol-K.

The 81-mm mortar was assumed to have a chamber volume of 0.001063 m^3 (64.88 $in.^3$), and the 4.037 kg (8.9-lb) projectile was assumed to have a travel of 1.006 m (39.6 in.). The bore resistance was assumed to be 0.689 MPa (100 psi) at all points. It was assumed that 0.123 kg (0.271 lb) of M10 and 109 mg (0.00024 lb) of black powder were used. The standard calculation resulted in a muzzle velocity of 288 m/s (944 ft/sec), a maximum breech pressure of 75.1 MPa (10.89 kpsi), a base pressure at shot ejection of 13.1 MPa (1.9 kpsi), and a muzzle gas temperature at shot ejection of 1939 K.

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