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**MODULAR ARTILLERY CHARGE SYSTEM (MACS) COMPATIBILITY
WITH THE 155-mm M114 TOWED HOWITZER**

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14. ABSTRACT The M114 155-mm towed howitzer has been obsolete and purged from the U.S. Army inventory, but is still in use at Yuma Proving Ground for test purposes. The Modular Artillery Charge System (MACS) replaces the bag M3 and M4 charges, which are being exhausted in the Army inventory. The MACS was not developed to be compatible with the M114 howitzer and was not tested. To support continued operations at the proving ground after the M3 and M4 charge stocks are no longer available, compatibility of MACS with the M114 howitzer was evaluated. This report documents the analytical phase of the evaluation, to be followed by a future text phase verifying the analytical evaluations prior to use by the proving ground.				
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INTRODUCTION

The U.S Army counter-battery radar, AN/TPQ-36 and -37 FIREFINDER, was evaluated by testing that uses 155-mm M114 towed howitzers, firing specific M3 and M4 propelling charge zones, in scenarios varying from single weapon firings up to weapons fired simultaneously so that as many as 10 projectiles are in the air and radar field of view at the same time. The continental United States (CONUS) stocks of these charges will expire this fiscal year, FY04 and early FY05. The replacement for the M3 and M4 charges for the current 155-mm artillery are the M231 and M232 Modular Artillery Charge System (MACS) increments. The MACS increments have been Type Classified Standard and support the current active 155-mm artillery systems (including the M198 towed, the M777 lightweight towed, and the M109A5 and M109A6 "Paladin" self-propelled). The M114 howitzer was designated obsolete for the U.S Army inventory and MACS was not intended or evaluated to support that system.

To support continuance of FIREFINDER evaluation at proving grounds and the future replacement radar (AN/TPQ-47 FIREFINDER under development), an evaluation to qualify the use of MACS in the M114 howitzer in the proving ground environment was requested by the Yuma Proving Ground Test Director. This evaluation was to consist of two parts. Part I was an analytical evaluation of the M114 howitzer firing the MACS, the results being documented in this technical report. Part II was to be a live fire verification of the results of part I, to be performed at a later date, but prior to any usage of the MACS/M114 combination.

MODELING

The modeling effort consisted of two phases: First was the interior ballistic modeling to generate predicted breech pressure versus time table and projectile velocity for each candidate MACS combinations. This data was then used to generate the breech force curve that is the primary input to the recoil mechanism model. Second was the recoil mechanism modeling of the M6 recoil mechanism used on the M114 howitzer to simulate its response to the breech force curves generated from the interior ballistic modeling.

Interior Ballistic Modeling

The M4 "white bag" as well as the MACS M231 and M232 were modeled using the Interior Ballistics of High Velocity Guns, version 2 (IBHVG2), a lumped-parameter interior ballistic computer code. IBHVG2 is used primarily for calculating such properties as projectile velocity and chamber pressure as a function of time. IBHVG2 compiles the data provided by input decks that contain the basic information relating to the cannon, the projectile, the primer, and the propelling charge. Specific input decks were generated for the M4 and MACS across all 155-mm weapons that they were intended to be fielded with; however, MACS was only intended to be fielded with weapons that are 39-caliber and larger (there were no plans to field or test MACS in the M114 howitzer). Therefore, a new set of input decks were required for MACS in the M114 in support of this effort. These were based upon the fairly robust decks that existed for MACS as well as a comparison of firing data of the M4 and MACS in various weapon systems.

The M231 contains a fast-burning low-energy propellant similar to those contained in the M3 "green-bag" and the M4 "white-bag." The M231 is fired either singly (charge-1) or in pairs (charge-2) to engage short-range targets. From a muzzle velocity standpoint, M231 charge-1 is equivalent to M3 or M4 charge-4, while M231 charge-2 is equivalent to M4 charge-6. The M232 contains a slow-burning high-energy propellant similar to that contained in the M203 "red-bag." The M232 is fired in groups of three or more increments from charge-3 (three M232s) to charge-5 (five M232s) to engage intermediate-range and long-range targets. The M114 howitzer would be limited to charge-3, and from a muzzle velocity standpoint, M232 charge-3 is equivalent to M4 charge-7.

A total of six IBHVG2 simulations were used. Report M4 was taken from a Technical Note* from the interior ballistic work sheets used at the time. IB M4 was a simulation of the M4 charge-7 at 145°F to gauge the validity of the model's response to the IBHVG2 simulations by comparison with the Report M4 simulation and results. MACS C1 corresponds to M231 charge-1, MACS C2 corresponds to M231 charge-2, and MACS C3 corresponds to M232 charge-3. One additional MACS simulation was performed because the slow-burning M232 at charge-3 exceeded weapon limitations discussed later in this report. MACS C3Mx corresponds to a mixed charge-3 where one of the M232 increments was replaced by a fast-burning M231 increment (placed forward of the charge-stack towards the projectile) -- *please note that this was not an approved combination for existing fielded 155-mm artillery weapons, it was only recommended for remote firings from the M114 howitzer at proving grounds.* The muzzle velocity calculated by the simulated charge configurations are provided in table 1.

Table 1
Modeled charge muzzle velocity

<u>Charge</u>	<u>Simulation muzzle velocity (m/s)</u>
Report M4	564
IB M4	561
MACS C1	301
MACS C2	450
MACS C3	547
MACS C3Mx	544

M6 Recoil Mechanism Modeling

Model Verification

The mathematical model of the M6 recoil mechanism presented in the technical note was converted into a Microsoft Excel spreadsheet. The simulation of the M6 recoil mechanism was of the lumped parameter type using constant discharge coefficients for recoil brake hydraulic flows and discounting gross weapon displacements or flexures. To verify the spreadsheet based model to the original modeling, the breech force curve provided in the technical note was used for both models and the simulated responses compared. The results are provided in table 2.

*"Calculations of Resisting Constants for 155mm Howitzer, M6," Technical Note Report 28-63, Research & Engineering Division, Rock Island Arsenal, Rock Island, Illinois, September 1963.

Table 2
Model results - technical note versus spreadsheet

	0 deg quadrant elevation (QE)		63 deg QE	
	Recoil velocity (ft/s)	Recoil displacement (in.)	Recoil velocity (ft/s)	Recoil displacement (in.)
Tech note	49.6	56.0	48.3	40.2
Spreadsheet	49.9	55.0	48.4	38.6

Seven charge configurations were simulated by interior ballistic modeling techniques. IB M4 Adj. was a modification to the IB M4 simulation to adjust the breech pressure during the in-bore period scaled to match the 70°F peak chamber pressure by applying the ratio of the two peak pressures. This was done to avoid performing another simulation run. For all of the simulated breech force curves evaluated, the weapon impulse was calculated. The results are provided in table 3.

Table 3
Modeled breech force generated weapon impulse

<u>Charge</u>	<u>Weapon impulse (lbf – sec)</u>
Report M4	7376.2
IB M4	7484.8
IB M4 Adj.	7023.5
MACS C1	3227.6
MACS C2	5393.1
MACS C3	8040.4
MACS C3Mx	6954.2

To evaluate the difference in the interior ballistic modeling approach of that used in the technical note and the IBHVG2 code used for all of the other simulations, the simulation Report M4, IB M4, and IB M4 Adj. were compared against each other and their simulated weapon performance. The two approaches exhibit a fundamental difference in rate of pressure rise with the IBHVG2 code simulation shifted to the right. Also, the IBHVG2 code predicted a lower muzzle velocity than that used in the technical note approach.

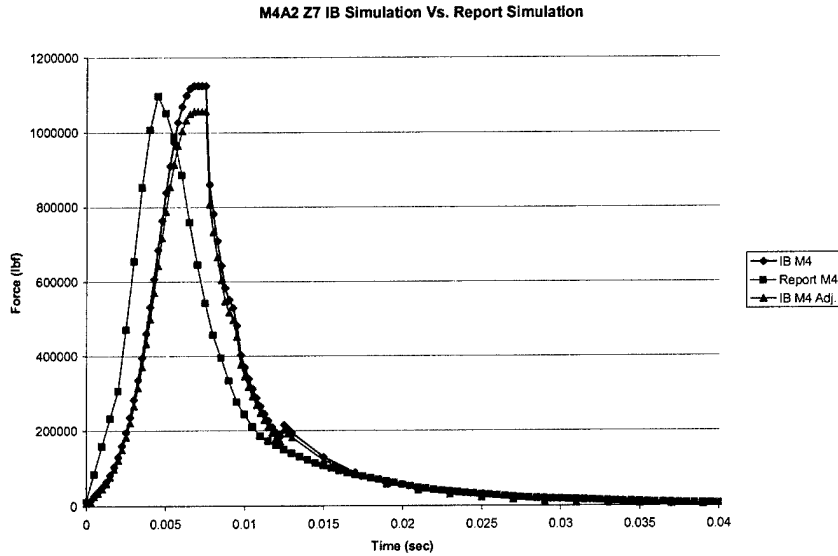


Figure 1
Report M4 simulation versus IBHVG2 simulation

The breech force curves for the technical note simulation and the IBHVG2 code simulation were applied to the spreadsheet model with the results plotted in figures 2 and 3. The recoil brake forces were higher, but the recoil displacements were similar. This raised the question to the validity of using the simulations generated by the IBHVG2 code. The IBHVG2 code simulation developed higher recoil brake force than the technical note for both long and short recoil modes. Both simulations were modeled for the hot, 145°F, charge condition based on muzzle velocity. Peak breech pressure for the IBHVG2 code simulation was similar to test data, the technical note peak was similar to the 70°F.

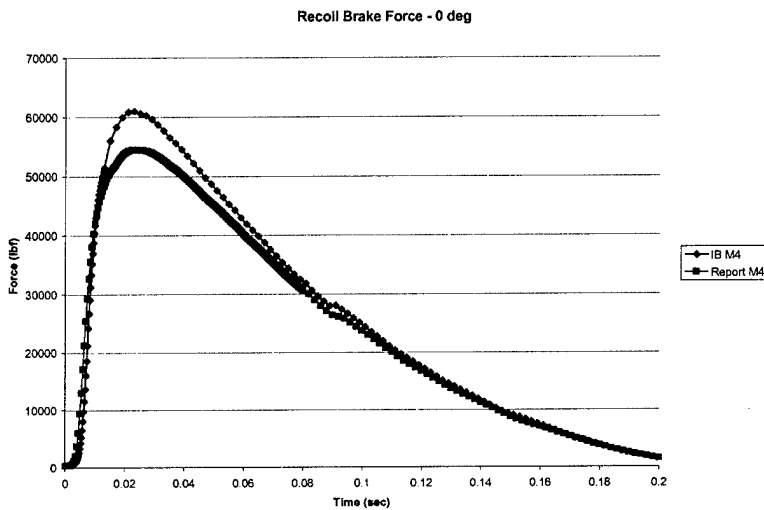


Figure 2
Simulated recoil brake force, 0 deg QE, Report M4 versus IBHVG2 simulation

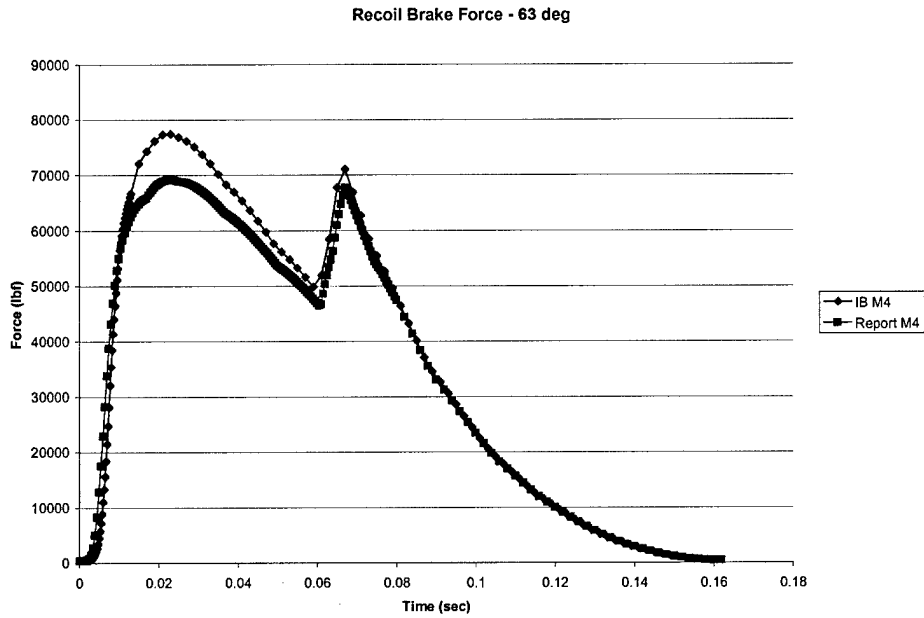


Figure 3
 Simulated recoil brake force, 63 deg QE, Report M4 versus IBHVG2 simulation

Decreasing the IBHVG2 code M4 simulation by the breech pressure ratio of the technical note peak and the IBHVG2 code peak, the simulated recoil brake forces are very similar and are plotted in figures 4 and 5.

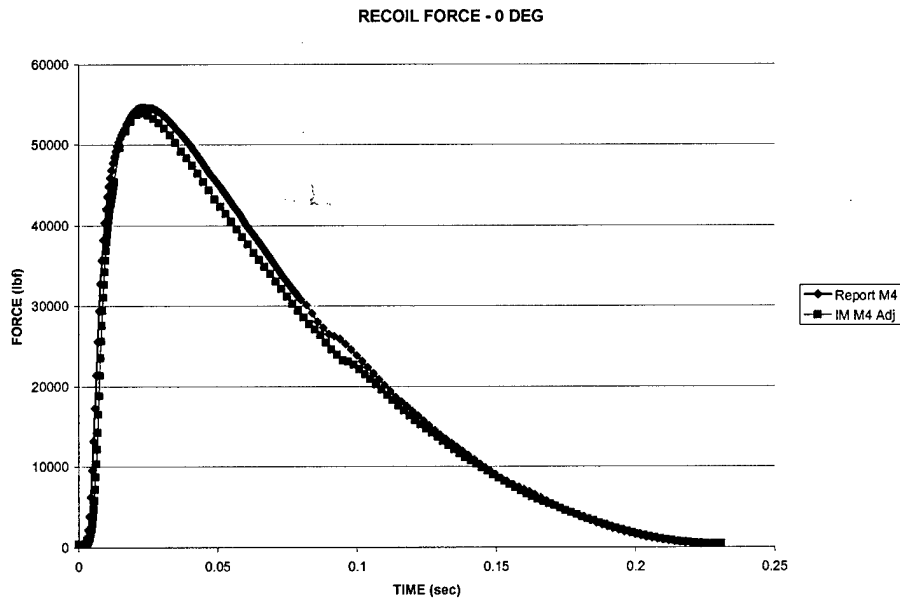


Figure 4
 Simulated recoil brake force, 0 deg QE, Report M4 versus adjusted IBHVG2 simulation

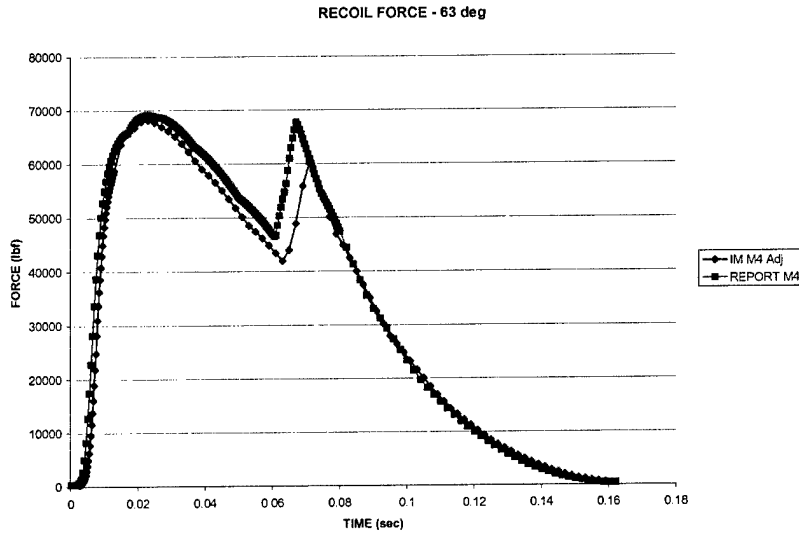


Figure 5
 Simulated recoil brake force, 63 deg QE, Report M4 versus adjusted IBHVG2 simulation

The adjusted IBHVG2 code breech pressure simulation when applied to the spreadsheet simulation matches the simulation provided in the technical note for both recoil brake force and recoil displacement curves. This demonstrates that the M6 recoil mechanism model and the interior ballistic simulations using the worksheet and the IBHVG2 code will provide similar results regardless of the combination. In all cases, the simulation predicted recoil displacement was similar for all M4 charge simulations used. For the evaluation of the candidate MACS charge combinations, the maximum recoil brake force of the Report M4 interior ballistic simulation shall be used as the limit given the condition of the weapons at the proving grounds. This limit is 69,200 lbf. The three M4A2 charge simulations at both 0 and 63 deg gun elevation are plotted in figure 6.

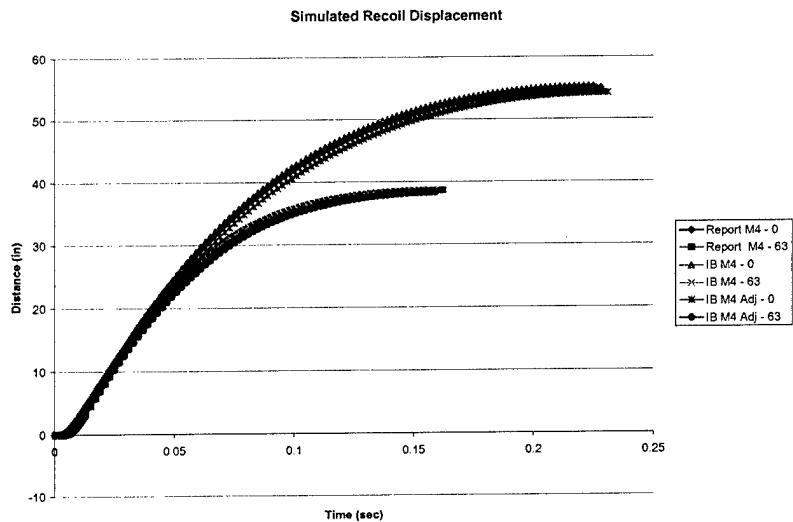


Figure 6
 Simulated recoil displacement summary, report, and IBHVG2 M4 simulations

Based on the technical note evaluation criteria being the recoil displacement, the spreadsheet was considered validated.

Candidate MACS Solution Evaluation

The breech force curves for the four candidate MACS solutions are plotted in figure 7 with the technical note standard breech force curve provided for comparison.

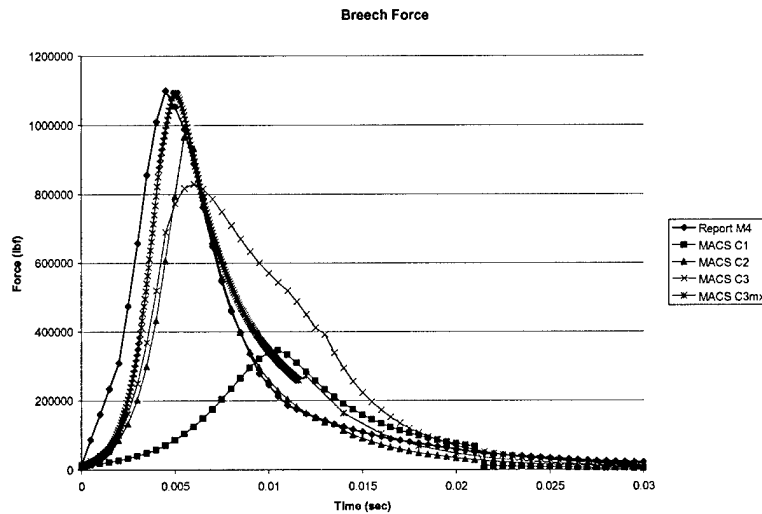


Figure 7
Breech force curves for MACS candidates

The spreadsheet simulation of the M114 howitzer's M6 recoil mechanism was run with each breech force curve to evaluate the weapon response.

The first MACS candidate was a single M231 increment. The breech force curve, MACS C1, generated from the IBHVG2 code simulation was applied to the spreadsheet simulation at both 0 and 63 deg QE corresponding to long and short recoil mechanism modes of operation. In both cases, the predicted performance was well within the limit of the M4A2 performance as seen in figure 8. This charge combination (one M231) was predicted safe for all elevations and charge temperature conditions.

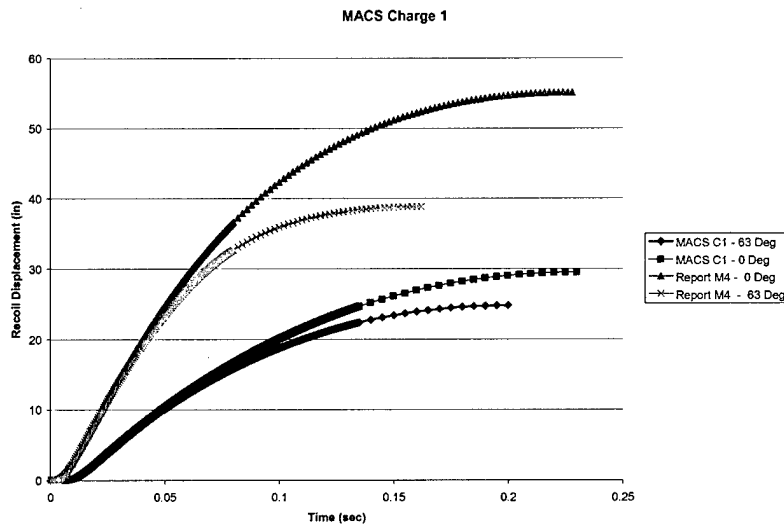


Figure 8
Simulated recoil displacement, MACS C1 option

The second MACS candidate was made up of two M231 increments. The breech force curve, MACS C2, generated from the IBHVG2 code simulation was applied to the spreadsheet simulation at both 0 and 63 deg QE corresponding to long and short recoil mechanism modes of operation. In both cases, the predicted performance was well within the limit of the M4A2 performance as seen in figure 9. This charge combination (two M231s) was predicted safe for all elevations and charge temperature conditions.

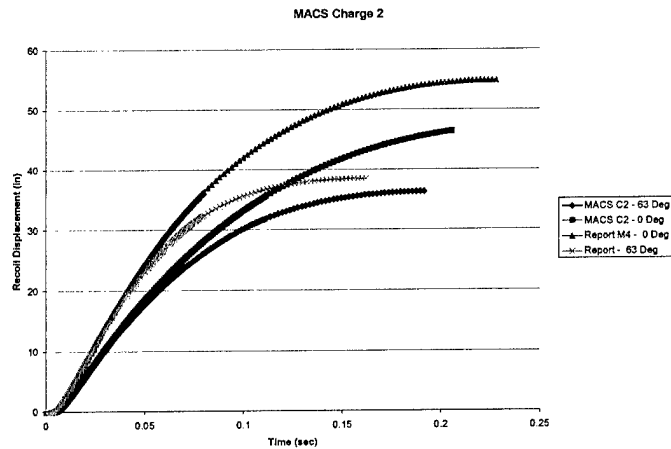


Figure 9
Simulated recoil displacement, MACS C2 option

The third MACS candidate was made up of three M232 increments. The breech force curve, MACS C3, generated from the IBHVG2 code simulation was applied to the spreadsheet simulation at both 0 and 63 deg QE corresponding to long and short recoil mechanism modes of operation. In both cases, the predicted performance exceeded the limit of the M4A2 performance as seen in figure 10. The predicted recoil brake force is plotted in figure 11. The recoil brake throttling groove ended while the weapon was still recoiling resulting in the spike in long recoil mode and greatly elevated humps in short recoil mode. This charge combination (three M232s) was predicted unsafe for all elevations and charge temperature conditions and would result in catastrophic failure of the weapons recoil mechanism and can not be used.

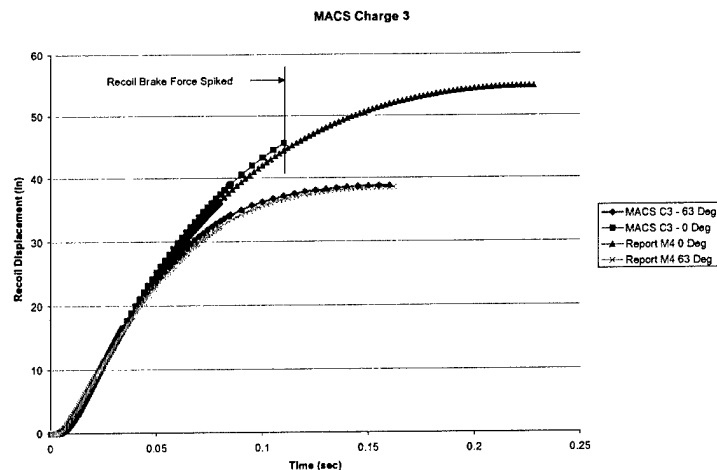


Figure 10
Simulated recoil displacement, MACS C3 option

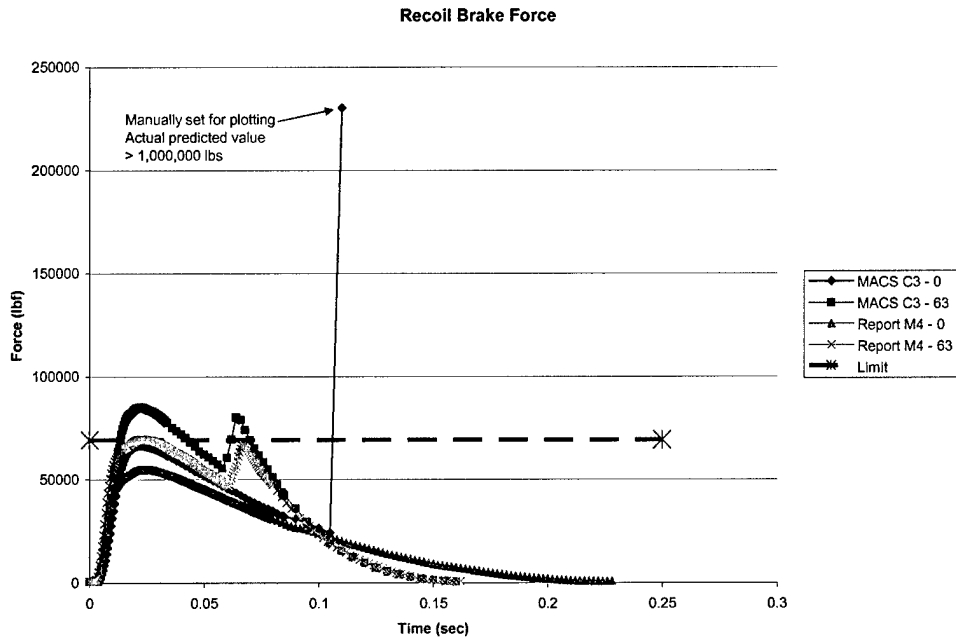


Figure 11
 Simulated recoil brake force, MACS C3 versus Report M4

The fourth MACS candidate was a mixed charge-3 made up of two M232 increments and one M231 increment (with the M231 increment being the most forward of the three near the projectile). The slow-burning propellant of the M232 exceeds weapon limitations when three M232s are fired (as shown in the prior paragraph), and firing three M231s would exceed pressure limitations. Therefore, one of the M232's was replaced by a fast-burning M231 increment to increase its pressurization rate -- *please note that this was not an approved combination for existing fielded 155-mm artillery weapons, it was only recommended for remote firings from the M114 howitzer at proving grounds*. The breech force curve, MACS C3Mx, generated from the IBHVG2 code simulation was applied to the spreadsheet simulation at both 0 and 63 deg QE corresponding to long and short recoil mechanism modes of operation. In both cases, the predicted performance matched or was below the limit of the M4A2 performance as seen in figure 12. The predicted recoil brake force is plotted in figure 13. Though the MACS C3mx at 63 deg QE slightly exceeds the limit of the M4A2 performance, peak force of 70,660 lbf versus 69,200 lbf, this charge combination (two M232s plus one M231) was predicted safe for all elevations and at a maximum charge temperature condition of 70°F.

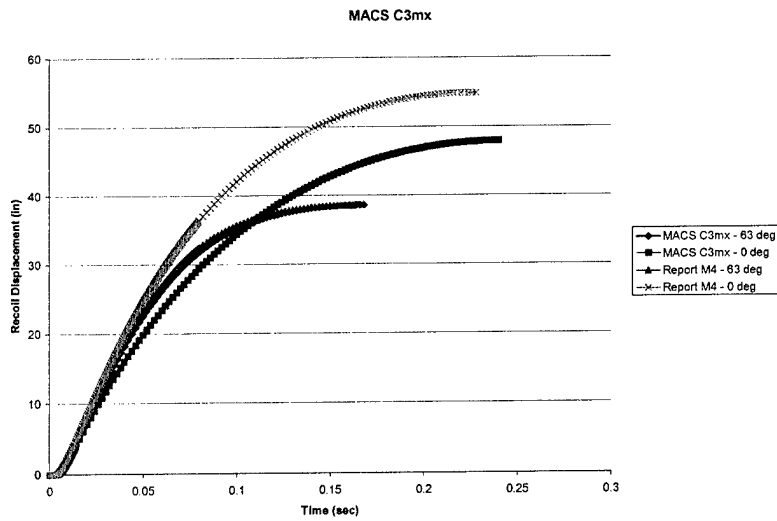


Figure 12
 Simulated recoil displacement, MACS C3Mx option

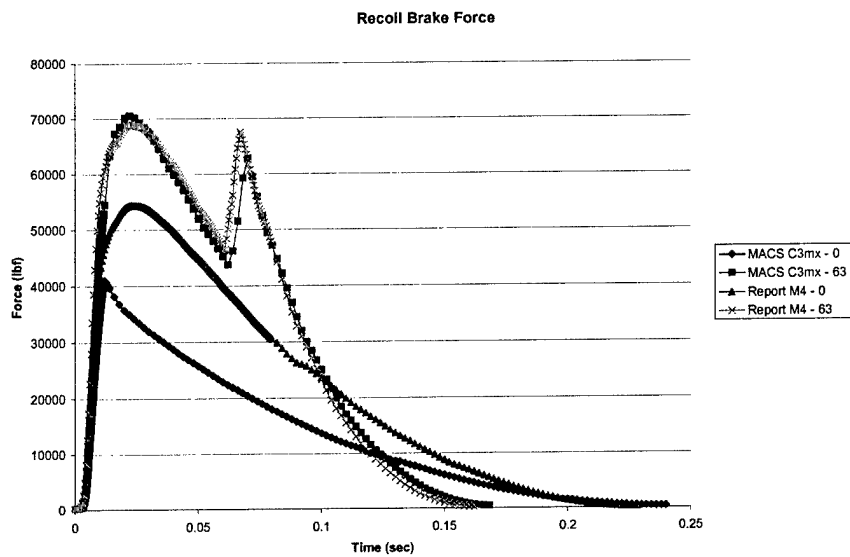


Figure 13
 Simulated recoil brake force, MACS C3Mx versus Report M4

Candidate Performance Summary

To summarize the evaluation of the four MACS candidate solutions, the respective performance of each is plotted against the Standard M4 for recoil displacement and recoil brake force. In each instance, the MACS C3 case using three M232s exceeds the Standard M4 (figs. 14 through 17).

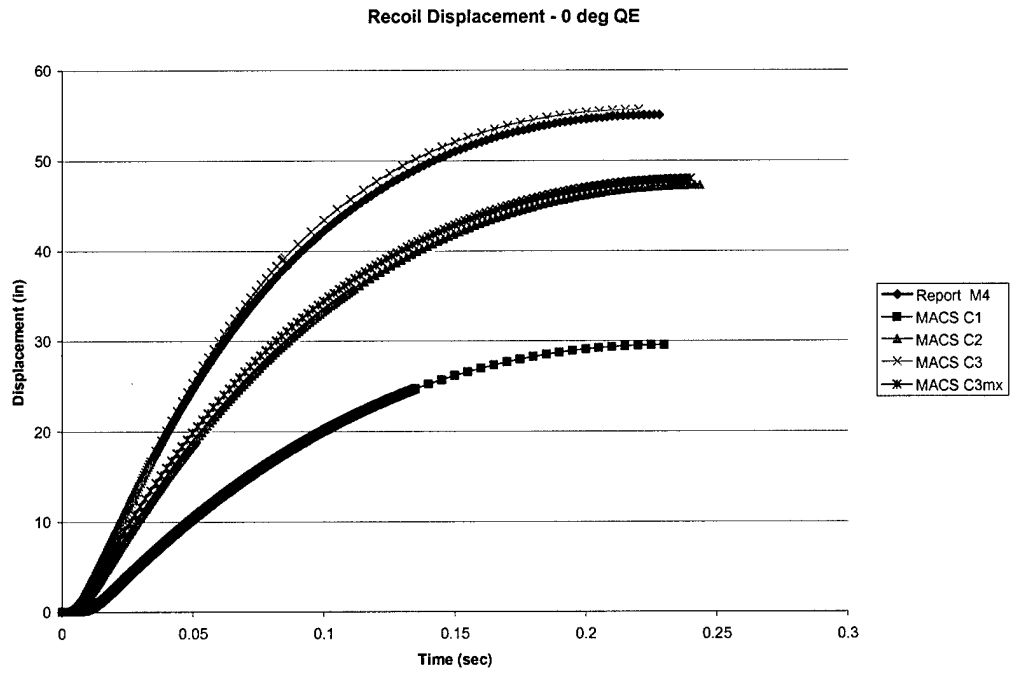


Figure 14
Summary simulation recoil displacement for options – 0 deg QE

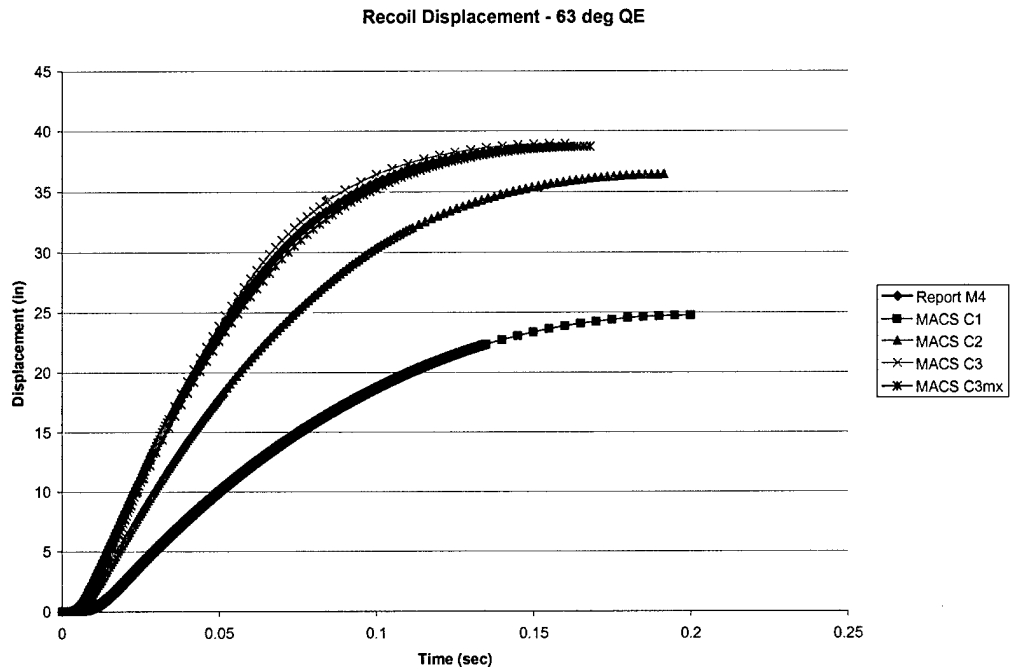


Figure 15
Summary simulation recoil displacement for options – 63 deg QE

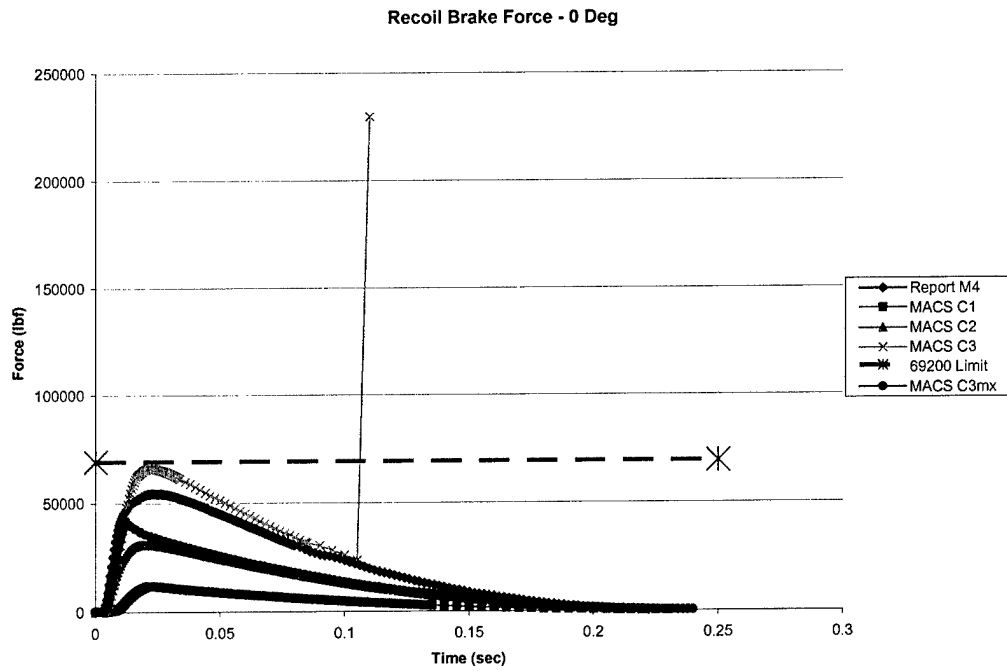


Figure 16
Summary simulation recoil brake force for options – 0 deg QE

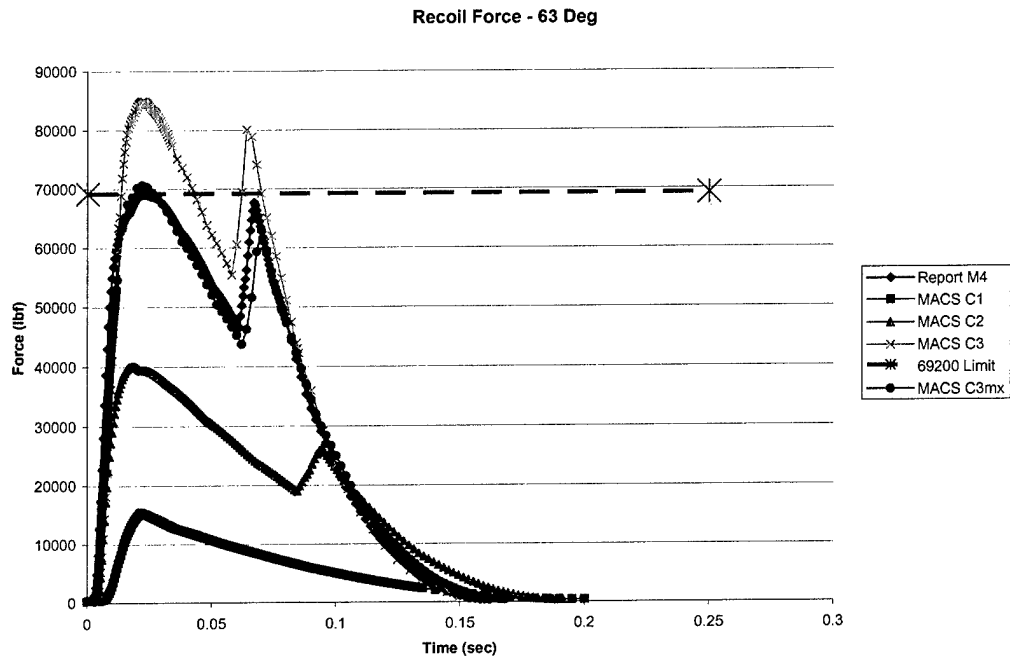


Figure 17
Summary simulation recoil brake force for options – 63 deg QE

CONCLUSIONS

For the purpose of firing MACS increments in 155-mm M114 towed howitzers in the unmanned proving ground environment, the following combinations are safe and allowable to be fired given successful verification of their performance by instrumented live firing.

Allowable combinations and their restrictions

MACS combination	QE	Temperature
One M231	All	-50°F to +145°F
Two M231s	All	-50°F to +145°F
Two M232s and one M231 *	All	-50°F to +70°F maximum

**Please note that this is not an approved combination for existing fielded 155-mm artillery weapons, it is only recommended for remote firings from the M114 howitzer at proving grounds.*

RECOMMENDATIONS

Safety of Use

Pending the verification of performance by actual test firing, the MACS combinations in shown previously are safe to be fired in the 155-mm M114 towed howitzer under the specified limiting conditions.

Verification Test Outline

Instrumentation

- Recoil displacement, maximum (in.)
- Recoil brake rod pull versus time by load cell (lbf, sec)
- Chamber pressure, peak, copper crusher (psig)
- Muzzle velocity (m/s)

Materiel to Test

- 155-mm M114 towed howitzer
- M231 MACS Increments
- M232 MACS Increments
- M107 projectiles, inert
- Fuze, dummy
- Primer, M82

Test Matrix

Simulation verification test matrix

Test round numbers	Increment combination	Charge temperature (°F)	QE (mils)
1-3	1 x M231	Discretion of Test Director	0 – 350 or 800 - 1150
4-6	2 x M231	Discretion of Test Director	0 – 350 or 800 - 1150
7-9	2 x M232 + 1 x M231	70	0 – 350
10-12	2 x M232 + 1 x M231	70	800 - 1150

Required Data

Data Taken For Each Round

- Muzzle velocity for each round
- Peak chamber pressure for each round
- Maximum recoil displacement for each round
- Recoil brake rod pull versus time for each round

Data Taken Prior to Test/As Needed

- Still photographs of test set-up and test instrumentation
- Still photographs of any test incidents

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