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EFFECT OF WEAR-REDUCING ADDITIVES ON HEAT TRANSFER INTO THE 155--ETC(U)
FEB 77 J R WARD, T L BROSSEAU

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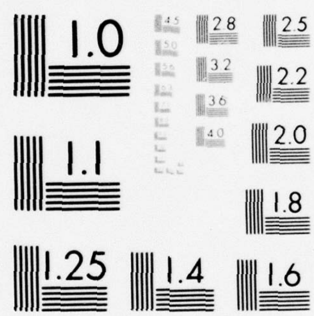
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(Supersedes IMR No. 496)

EFFECT OF WEAR-REDUCING ADDITIVES ON HEAT TRANSFER INTO THE 155mm M185 CANNON

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February 1977

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Heat transfer measurements were made in a 155mm M185 cannon equipped with fast response thermocouples. The thermocouples were constructed by welding thin constantan wires onto gun steel. The thermocouples were placed 101cm from the rear face of the tube at four different distances from the bore surface. From measurements of the temperature rise at 100 ms, the total heat input to the gun barrel at 101cm RFT was determined. In addition to temperature measurements, the ignition delay, chamber pressure and muzzle velocity were determined for each round. In selected rounds

the initial negative differential pressure was also determined.

Heat transfer measurements were made with the base-ignited XM201E2 charge and the center-core ignited XM201E1, XM119E4, XM203E2, and M119 charges. The heat transfer results suggested that the wear-reducing liner in the XM201E2 charge did not exert any influence on heat transferred to the barrel. It was noticed that the XM201E2 charge had an ignition delay of more than 200 ms. By shortening the ignition delay the wear-reducing liner in the XM201E2 charge reduced heat input in the same fashion as the center-core ignited XM201E1 and XM119E4 charges. The wear-reducing liner in the XM203E2 charge was the most effective.

Despite the reduction in heat transfer for the XM201E2 with the shorter ignition delay, the heat input is still significantly greater than the heat input of the M119 charge. It was found that the addition of an extra liner of TiO_2/wax to the XM201E2 charge with a black powder igniter resulted in heat input comparable to the M119. The addition of the extra liner to the XM203E2 charge reduced the heat input in like fashion. This suggests the possibility that the wear life of both the zone 7 XM201E2 charge and the zone 8 XM203E2 charge can be increased by modifying the additive.

Temperature measurements and initial negative differential pressures were taken for M6 and M15 propellant versions of the XM201E2 charge. For the M6 version, heat input was similar to the M119 charge and no negative differential pressures were observed at 25mm stand-off. The M15 version had ignition delays greater than 300ms which meant that significant preheating occurred. Nonetheless, it is felt that the wear life of the M15 version should be similar to the M119 charge.

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I. INTRODUCTION

The 155mm propelling charge, XM201E2, is in the final stages of engineering development as a replacement for the M119 propelling charge. Among the requirements set for acceptance of the XM201E2 charge is that the wear life of the gun tube must not be reduced. Since the XM201E2 charge is composed of triple-base M30A1 propellant while the M119 charge consists of single-base M6 propellant, the developers of the XM201E2 charge included a TiO_2/wax wear-reducing liner to try to insure that the wear life of both charges would be the same. During the wear test of the XM201E2 charge, it was soon evident that the XM201E2 charge was more erosive than the M119 charge.

A hypothesis was tendered that the wear-reducing liner in the XM201E2 charge was not exerting any influence on the wear rate. In order to test this hypothesis and to suggest ways to reduce the erosiveness of the XM201E2 charge, heat transfer measurements were made in a 155mm M185 cannon firing various propelling charges equipped with and without wear-reducing additives. Similar measurements were performed previously in a 37mm gun and in the 105mm M68 tank cannon.[1,2] In both guns the wear-reducing additives reduce the erosion rate of the cannon, and the heat transfer measurements detected significant differences in the total heat transferred to the gun barrel in the presence of the wear-reducing additives.

II. EXPERIMENTAL

Temperature distributions in the M185 cannon were measured by means of four thermocouples inserted at different radial distances from the bore surface, but all were located at the same axial distance from the rear face of the tube. The thermocouples were made by spot-welding 0.13mm diameter constantan wires onto the gun steel. A detailed description of the technique has been previously published;[3] of particular note is the care needed to measure properly the distance from the constantan-steel junction to the bore surface.

The test firings were conducted with cannon serial number 22541 from which 730 rounds had been previously fired. The multiple stargage measurement and inspection data are given in Appendix A. The constantan wires were placed 90° apart at a distance of 101cm (39.6 inches) from

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[1] *T. L. Brosseau and J. R. Ward, "Reduction of Heat Transfer to Gun Barrels by Wear-Reducing Additives," J. Heat Transfer, 610-614 (1975).*

[2] *T. L. Brosseau and J. R. Ward, "Effect of Wear-Reducing Additives on Heat Transfer in the 105mm M68 Tank Cannon," BRL Memorandum Report No. 2698, November 1976, AD #B015308L.*

[3] *T. L. Brosseau, "An Experimental Method for Accurately Determining the Temperature Distribution and Heat Transferred in Gun Barrels," BRL Report No. 1740, September 1974, AD #B000171L.*

the rear face of the tube. The four thermocouples were 0.81, 1.0, 1.5, and 2.6mm from the bore surface (corresponding to 32, 41, 60, and 102 mils from the bore surface), and each thermocouple was placed over a groove. The chamber pressure was measured with a 607C Kistler gage located in the spindle. For selected rounds differential pressures were measured with an additional 607C Kistler gage located at 85.5cm (33.6 inches) from the rear face of the tube. The velocity of the projectiles was measured with two coils a known distance apart. The distance from the muzzle of the gun to the first coil was 25.3m.

Table I summarizes pertinent characteristics of the propelling charges used in this investigation. The two charges with M1 propellant were used as "clean-out" rounds. All charges were conditioned overnight at 21°C (70°F).

The firing sequence is listed in Appendix B. All rounds equipped with TiO_2/wax liners were followed by clean-out rounds. Clean-out rounds were also fired to start each morning and afternoon's firing. The zone 7 charges were fired with a 6mm stand-off except where noted. All XM203E2 firings had a 25mm stand-off.

Sufficient M107 projectiles were unavailable, therefore, M107 projectiles modified for firing at zone 8 had to be used instead. Standard M107 projectiles were fired with the XM201E2 and the M119 charges.

The rationale behind the firing sequence in Appendix B is summarized below by listing objectives and the tests made to meet those objectives:

Objective	Tests
1. Compare heat input for the XM201E2 charge with the M119 charge.	XM201E2 and M119 charges with both M107 and M107 modified projectiles.
2. Measure influence of wear-reducing additives on heat transfer.	XM201E1, XM201E2, XM119E4, and XM203E2 charges with and without wear-reducing liners.
3. Test the influence of the projectile.	XM201E2 charge with the M107, M107 modified, M549 RAP, and the M483A1 projectiles.
4. Compare heat input of base-ignited M6 and M15 propellant with the center-core ignited M119.	Based-ignited M6 and M15 charges were fabricated and fired.
5. Test the effect of ignition delay.	Clean-burning igniter in the XM201E2 charge replaced with black powder igniter from the M4A1 charge.

Table I. Pertinent Characteristics of Propelling Charges

Designation	Lot No.	Propellant	Ignition Mode	Wear-Reducing Additive	Dia, cm	length/ diameter
XM201E2	IND-E-140-74	M30A1	base, CBI[a]	TiO_2/wax, two-piece	13.0	5.6
XM201E1	IND-E-105-73	M30A1	center-core, CBI, benite strands	TiO_2/wax, two-piece	15.5	3.8
M119	IA-B-39740A	M6	center-core, CBI, benite strands	None	15.5	4.0
XM119E4	RAD-64654	M30A1	center-core, CBI, benite strands	TiO_2/wax, one-piece	15.5	3.2
XM203E2	PA-E-09612	M30A1	center-core, BP[b]	TiO_2/wax, one-piece	15.5	4.9
M4A1	IA-39519-57	M1	base, BP	None	-	-
M4A2	RAD-69383	M1	base, CBI	None	-	-
XM201E2-M6	IND-E-140-74	M6	base, CBI	None	14.0	5.0
XM201E2-M15	IND-E-140-74	M15	base, CBI	None	14.0	5.3

[a] Clean burning igniter

[b] Black powder igniter

Objective	Tests
6. Attempt to reduce heat input of XM201E2 charge.	XM201E2 charge with flaps in the TiO_2/wax liner with ablative coolant, and with a TiO_2/wax liner against the chamber wall.

Table II correlates these test objectives with the individual tests in Appendix B.

Three modifications were made to the XM201E2 to try to reduce the heat input to the barrel. Two modifications were based on previous experience with the TiO_2/wax liner in the 105mm M68 tank cannon. In contrast with the liner in the XM201E2 charge, the TiO_2/wax liner in the M392 APDS round rests flush against the chamber (in this situation, the cartridge case), the liner has flaps folded over the forward end of the propelling charge, the TiO_2/wax side of the liner faces the propellant, and the additive rests against the base of the projectile. The first modification to the XM201E2 liner was to incorporate flaps on the forward end of the zone 7 segment of the XM201E2 charge. The second modification consisted of the construction of a TiO_2/wax liner with the same diameter as the chamber, was equipped with flaps, and was pushed against the rear of the projectile. This modification is referred to as a TiO_2/wax "cap". The cap was made from two TiO_2/wax liners from the 105mm tank cannon. The flaps were lengthened to 9cm; the TiO_2/wax cap was 32cm long including the flaps and it weighed 0.24kg (0.53 pounds). The third modification was to eliminate the TiO_2/wax liner and replace the liner with "ablative coolant," a gelled silicone grease developed by Calspan Corp. A liner of gelled silicone was made by spooning 0.45kg (1.0 pounds) of gelled silicone into a polyethylene bag. The liner was approximately 25mm x 25mm and it was taped to the forward end of the propelling charge.

III. RESULTS

Figure 1 depicts a typical plot of temperature vs time at each thermocouple. The estimate of the net heat input was made from the temperature measurements at 100 milliseconds from initial pressure rise. At this time, no significant further heating of the barrel by the propellant gases is taking place, and axial heat conduction should also be negligible.

The total heat in a given volume of the gun barrel is given by

$$Q = \rho C V \Delta T , \qquad (1)$$

where Q = heat input in volume element, V
ρ = density of gun steel,
C = specific heat of gun steel,
V = volume,
ΔT = temperature rise of gun steel in volume element, V.

Table II. Correlating ID Numbers and Program Rationale

Charge	Projectile	Modification	ID Numbers
XM201E2	M107	None	64, 72, 87
M119	M107	None	99, 99A
XM201E2	M107 mod	None	53, 66, 74
M119	M107 mod	None	58, 79, 98
XM201E2	M549	None	83, 103
XM201E2	M483A1	None	85, 105
XM201E2	M107 mod	2.5cm stand-off	151, 153
XM201E2	M107 mod	w/o liner	52, 62, 70
XM201E2	M107 mod	w/o liner, BP igniter	91, 92
XM201E2	M107 mod	w/o liner, ablative coolant	88, 89
XM201E2	M107 mod	w/o liner, TiO_2/wax cap	107, 109
XM201E2	M107 mod	BP igniter	94, 101
XM201E2	M107 mod	BP igniter, TiO_2/wax cap	132, 134
XM201E2	M107 mod	flaps	118, 122
XM201E2	M107 mod	flaps, BP igniter	128, 130
XM201E2	M107 mod	M6 propellant	112, 116, 120
XM201E2	M107 mod	M6 propellant, 2.5cm stand-off	148, 150
XM201E2	M107 mod	M15 propellant	113, 117, 121
XM201E2	M107 mod	M15 propellant, 2.5cm stand-off	147, 149
XM201E1	M107 mod	None	56, 77, 96
XM201E1	M107 mod	w/o liner	55, 71, 76
XM119E4	M107 mod	None	60, 68, 81
XM119E4	M107 mod	w/o liner	59, 63, 80
XM203E2	M107 mod	None	137, 141
XM203E2	M107 mod	w/o liner	139
XM203E2	M107 mod	TiO_2/wax cap	143

Since the temperature in the gun barrel varies with radial distance into the gun tube, the net heat input into the gun barrel is computed as follows. Equation (1) is recast in differential form as:

$$dQ = \rho C \, \Delta T dV \quad . \tag{2}$$

For a unit axial length of one millimeter, the temperature is assumed to vary in the radial direction only, therefore

$$dQ = \rho C \, \ell \Delta T dA \quad . \tag{3}$$

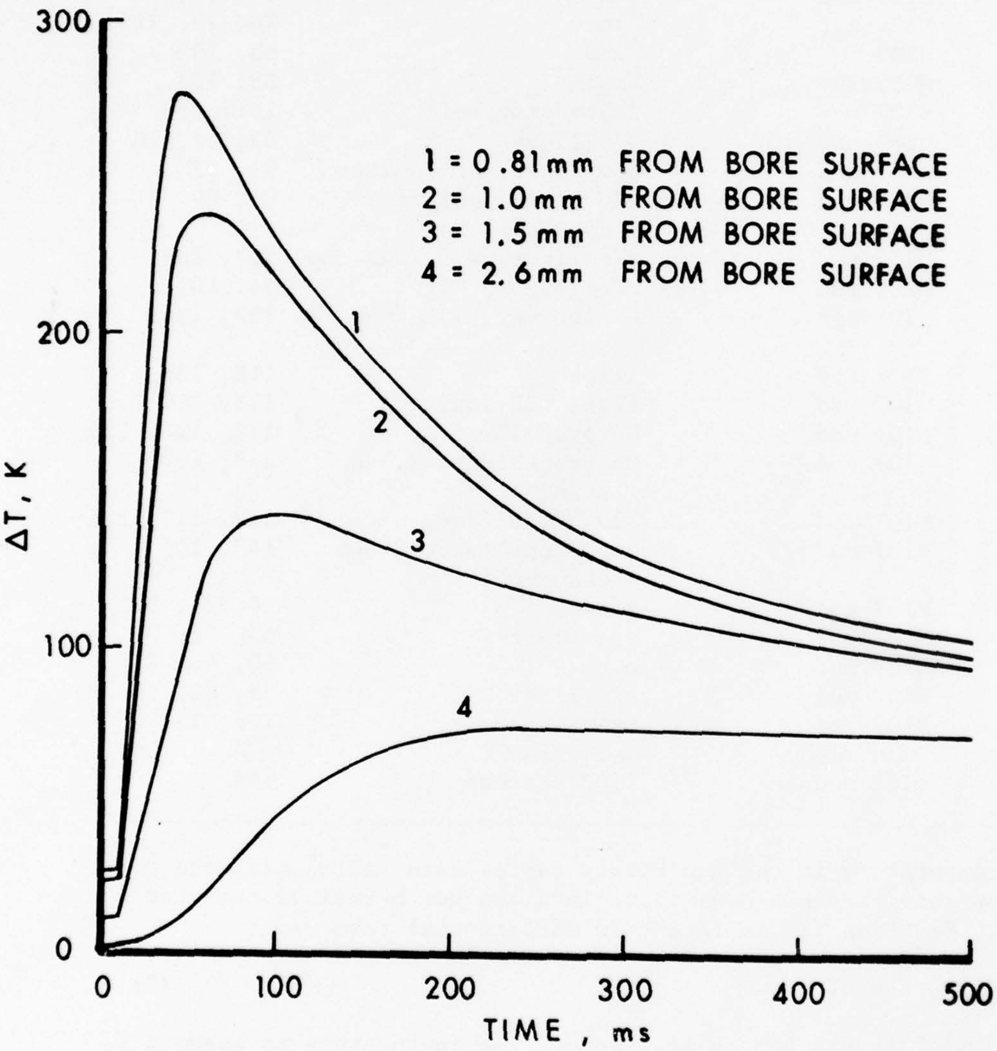

Figure 1. Temperature vs Time for Unmodified XM201E2 Charge (ID 74)

For a hollow cylinder of unit axial length,

$$dQ = \rho C \; 2\pi r \Delta T dr \quad , \tag{4}$$

and

$$Q = 2\pi\rho C \int_{r_i}^{r_o} r\Delta T dr \quad , \tag{5}$$

where r_i and r_o are the inside radius and outside radius of the gun barrel, respectively, and ΔT is the temperature rise at a distance r into the tube wall. The integral in Equation (5) is solved graphically by visually fitting a smooth curve through the four available values of $r\Delta T$ vs r and then measuring the area under the curve. The values of the density and specific heat of gun steel used in Equation (5) are $7.85 g/cm^3$ and 0.419 J/g-K.

Table III lists the heat transfer results for all firings. A single plot of $r\Delta T$ vs r was made for replicate firings using mean values of ΔT at each r. The XM201E2 charges with the clean-burning igniter had the widest variation in ΔT because of variations in ignition delay which resulted in different amounts of preheating. For the XM201E2 charges, plots of $r\Delta T$ vs r were made for each firing. The values of Q ranged from 820J to 780J. From a single plot of $r\Delta T$ vs r using the mean value of ΔT, Q equalled 813J. Appendix C contains ΔT vs r and $r\Delta T$ vs r plots for all the charges fired during these tests.

Appendix D lists the multiple stargage measurement and inspection data made at the conclusion of the tests. The vertical wear in the grooves at 101cm RFT (39.6 in) was negligible while the wear in the horizontal direction was less than 0.5mm. The vertical land wear was much more significant (2.3mm) especially considering the number of M4A2 and M4A1 charges included in the ninety-nine rounds fired in the course of these tests. These charges cause negligible erosion.

IV. DISCUSSION

The primary objective of these tests was to see if the wear-reducing additive in the base-ignited XM201E2 propelling charge was exerting any influence on the heat transferred to the gun barrel near the origin of rifling. As the results in Table III indicate, the wear-reducing liner does not reduce heat transfer significantly in this charge. In Table IV the effect of the wear-reducing liners for the XM201E2 charge and three center-core ignited charges is summarized along with previous measurements from the 105mm M68 tank cannon firing the M392 APDS round.[2] The polyurethane foam liner in the M392A2 round reduced the wear rate from 0.017mm/round to 0.005mm/round.[4] For the four 155mm propelling charges, the XM203E2 charge had the largest reduction in heat transfer. Table V compares some physical characteristics of the 155mm charges.

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[4] *R. O. Wolff, "Reduction of Gun Erosion, Part II, Barrel Wear-Reducing Additive," Picatinny Arsenal Technical Report No. 3096, August 1963.*

Table III. Summary of Heat Input to the M185 Cannon for Various 155mm Propelling Charges[a]

Charge	Modification	Q, J
XM201E2	None	813
XM201E2	w/o liner	824
XM201E1	None	701
XM201E1	w/o liner	750
XM119E4	None	702
XM119E4	w/o liner	764
XM203E2	None	702
XM203E2	w/o liner	793
M119	None	677
M6 version XM201E2		697
M15 version XM201E2		787
XM201E2	flaps	770
XM201E2	M4A1 igniter	712
XM201E2	M4A1 igniter, w/o liner	764
XM201E2	w/o std liner; TiO_2/wax cap	762
XM201E2	flaps, M4A1 igniter	721
XM201E2	M4A1 igniter std liner & cap	671
XM203E2	std liner and cap	651
XM201E2	M107 standard	764
XM201E2	M549	764
XM201E2	M483	762
XM201E2	Ablator	804
M119	M107 standard	677

[a]M107 modified projectiles unless otherwise noted.

Table IV. Effect of Wear-Reducing Liners on Heat Transferred to Gun Barrel

Charge	Q, J, with liner	Q, J, no liner	percent reduction
XM201E2	813	824	1
XM119E4	702	764	8
XM201E1	701	750	6
XM203E2	702	793	11
M392A2 round	372	426	13

Table V. Correlation Between Heat Transfer Results and Some Characteristics of the Propelling Charges

Charge	Propellant mass, kg (lbs)	Additive mass kg (ozs)	Charge length, cm (in)	Diameter cm (in)	Igniter	Ignition delay, ms	Q, J, no liner	Q, J, liner
XM201E2	7.80 (17.2)	0.23 (9.5)	71.6 (28.2)	13.0 (5.1)	base	210 (av of 6)	824	813
XM201E1	7.80 (17.2)	0.23 (9.5)	58.9 (23.2)	15.5 (6.1)	center-core	137 (av of 6)	750	701
XM119E4	7.94 (17.5)	0.31(11.0)	52.1 (20.5)	15.5 (6.1)	center-core	225 (av of 5)	764	702
XM203E2	11.8 (26.1)	0.50(17.5)	76.2 (30.0)	15.5 (6.1)	center-core	81 (av of 5)	793	702

Since marked heating of the gun barrel was noted during the ignition delay of the XM201E2 charge, experiments were done with the faster burning black powder igniter from the M4A1 charge in place of the clean-burning igniter on the XM201E2. These results are summarized in Table VI. It is clear the total heat absorbed by the gun is reduced in the presence of the faster-burning igniter. Another interesting point is that the wear-reducing liner in the XM201E2 now exerts significant influence on the heat input to the barrel (764 J for no liner to 712 J with the liner). In addition the heat input measured for the zone 8, XM203E2 charge, without liner, is now higher than the XM201E2 charge with a comparable ignition delay (793 for the XM203E2 vs 764 for the XM201E2). Nonetheless, the wear-reducing liner in the XM203E2 charge is still more effective at reducing the heat transfer (11 percent for the XM203E2 vs seven percent for the XM201E2 with the M4A1 igniter).

Three separate modifications were tried to improve the wear-reducing capability of the TiO_2/wax liner in the XM201E2. From Table VII one sees that the addition of flaps lowers the heat transfer to the gun barrel, but the addition of flaps to the XM201E2 charge with the fast-burning igniter does not further reduce the heat input to the barrel.

Table VI. Effect of Ignition Delay on Heat Transfer with the XM201E2 Charge

Charge	Igniter	Ignition Delay,ms	Q, J	Q, J, no liner
XM201E2	CBI	210 (av of 6)	813	824
XM201E2	BP	78 (av of 4)	712	764

Table VII. Effect of Addition of Flaps to the TiO_2/Wax Liner in the XM201E2 Charge

Modification	Ignition delay, ms	Q, J
None	210 (av of 6)	813
M4A1 igniter	78 (av of 4)	712
Addition of flaps	300, 172	770
Addition of flaps + M4A1 igniter	110, 88	721

Another modification tested to mimic the TiO_2/wax liner in the 105mm M392 APDS round was a TiO_2/wax "cap". The TiO_2/wax cap fit snugly against the chamber wall, was equipped with flaps, had the TiO_2/wax side of the liner facing inward, and was placed at the base of the projectile. Results for the TiO_2/wax "cap" are presented in Table VIII. The TiO_2/wax cap was tested with unmodified XM203E2 and XM201E2 charges to also see the effect of adding additional wear-reducing additive. The addition of the cap to the XM201E2 charge without any liner was about equivalent to adding flaps to liner in the unmodified XM201E2 charge. For both the black powder ignited XM201E2 charge and the XM203E2 charge, the addition of the TiO_2/wax cap afforded an additional 6-7 percent reduction in heat transfer. Whether this additional reduction in heat transfer is due to the extra quantity of additive or to the placement of the TiO_2/wax liner with the cap cannot be ascertained.

Table VIII. Effect of TiO_2/Wax "Cap" on Heat Transferred to the Barrel

Charge	Modification	Q, J
XM201E2	None	813
XM201E2	w/o liner	824
XM201E2	w/o liner, TiO_2/wax cap	762
XM201E2	M4A1 igniter	712
XM201E2	M4A1 igniter + TiO_2/wax cap	671
XM203E2	w/o liner	793
XM203E2	None	702
XM203E2	TiO_2/wax cap	651

As one studies these results, it seems that the preheating of the gun barrel prior to propellant ignition interferes with the wear-reducing capability of the additive, but may not increase the erosivity of the propelling charge. If this is true, then comparison of the total heat inputs to determine erosivity are biased by the inclusion of the preheating. The reason for suspecting that the preheating may not be important is the high value of Q associated with the cool, triple-base M15 charge. If direct comparison of Q were a true measure of erosivity, then the M15 charge would be expected to be more erosive than the zone 8, XM203E2 charge containing M30A1 propellant. Also, the XM201E2 charge would be predicted to have a higher wear rate than the XM203E2 charge without any liner. As noted previously, if one compares the XM201E2 charge with black powder to the XM203E2 charge, then the expected trend is followed, namely, the XM203E2 charge without liner having a higher value of Q than the XM201E2 charge.

Under this assumption the heat input data for the XM201E2 with the M4A1 igniter are the proper values to compare with data for the other charges. The heat inputs for the various charges then fall into the classes shown below:

	Charge	Q, J
I.	XM203E2 w/o liner	793
II.	XM201E1 w/o liner	750
	XM201E2 w/o liner, M4A1	764
	XM119E4 w/o liner	764
III.	XM201E1	701
	XM201E2, M4A1	712
	XM119E4	702
	XM203E2	702
IV.	M119	677
	XM201E2, M4A1, TiO_2/wax cap	671
	XM203E2 + cap	651

The implication of this grouping is that the wear rate of the XM201E2 is of the order XM201E1 and XM119E4 without liners. In the M126 cannon, the XM119E4 charge without liner had a wear life of approximately 700 rounds. The next point is that the reduction in the ignition delay of the XM201E2 will make the TiO_2/wax effective in reducing heat transfer to the gun barrel, but the increase in wear life will be comparable to that experienced for the XM119E4 with additive, namely, a three-fold improvement. This will still not be in the range of heat input measured for the M119 charge. Another point to notice from Group III is that the wear-reducing liner in the zone 8, XM203E2 reduces the heat input such that the wear life of the zone 8 charge should be greater than the zone 7 XM201E2 charge.

The available erosion measurements for propelling charges tested are listed in Table X. The heat transfer results are consistent with the erosion data. The erosion rate of the XM201E2 charge is nearly the same as the XM119E4 charge without a liner. The zone 8 XM203E2 charge has a wear rate comparable to the XM119E4 charge. Finally, the M119 charge has the lowest wear rate as one would predict from the heat transfer measurements. The heat transfer results also predict that the addition of the TiO_2/wax cap to either the XM201E2 charge with a black powder igniter or to the XM203E2 charge will increase the wear life of these charges to that of the M119 charge.

Table IX. Summary of Erosion Data

Charge	Wear, cms/number of rounds	Wear Rate, cm/round	Cannon
XM201E2	0.13/500	2.6×10^{-4}	M185
XM119	0.14/660	2.8×10^{-4}	M126
XM119E4	0.11/1010	1.1×10^{-4}	M126
XM203E2	0.074/522	1.4×10^{-4}	XM199
M119	0.089/1000	0.9×10^{-4}	M185

The liner in the zone 8 charge is more efficient than in the zone 7 charges, since the XM203E2 without liner places 793J into the barrel vs approximately 760J for the group II charges, yet the heat input for the XM203E2 charge is virtually the same as the XM119E4 charge. From the data in Table V, some comparisons between the zone 7 and zone 8 charges can be made. The diameter of the XM119E4 and XM203E2 charges is the same; the ratio of the weight of the additive to the weight of the propellant is similar (0.042 for the XM203E2 to 0.039 for the XM119E4); the major difference is the length of the charge. The XM119E4 charge is 24cm shorter than the XM203E2 charge, thus the wear-reducing liner in the XM203E2 charge is much closer to the projectile base than is the liner in the XM119E4 charge. Previous results in the 105mm M68 cannon noted that the closer the liner was positioned to the projectile the lower the measured heat input.

The results for the charges containing single-base M6 and triple-base M15 propellant are listed in Table X. The heat transferred by the base-ignited M6 charge is slightly higher than the M119 charge, but it is significantly less than the XM201E2 charge. The heat transferred by the triple-base M15 charge is markedly higher than the M6 propellant charges due to the considerable preheating. On the basis of these heat transfer tests, the base-ignited M6 at least would be expected to have a similar wear rate to the M119 charge.

Table XI lists initial negative differential pressure measurements. For a 25mm stand-off distance, no negative differential pressures occur for the base-ignited M6 charge. A negative differential pressure of 8.6 MPa was noted for one of the two M15 charges fired with a 25mm stand-off.

Table X. Heat Transfer Measurements with M6 and M15 Propellant in the Propelling Charges

Charge	Propellant mass,kg Ignition Mode	Ignition delay,ms	Q, J
M119	center-core	170 (av of 3)	677
XM201E2 w/M6	base-CBI	237 (av of 3)	697
XM201E2 w/M15	base-CBI	346 (av of 3)	787
XM201E2 (unmodified)	base-CBI	210	813

Table XI. Initial Negative Differential Pressure Measurements for the M6, M15, and XM203E2 Charges

ID	Charge	ΔP, MPa, (psi)
112	M6, 6mm stand-off	23.5, (3406)
116	M6, 6mm stand-off	3.4, (493)
120	M6, 6mm stand-off	4.0, (575)
148	M6, 25.4mm stand-off	0 , 0
150	M6, 25.4mm stand-off	0 , 0
113	M15, 6mm stand-off	8.5, (1231)
117	M15, 6mm stand-off	0 , 0
121	M15, 6mm stand-off	5.9, (862)
147	M15, 25.4mm stand-off	8.6, (1247)
149	M15, 25.4mm stand-off	0 , 0
137	XM203E2	0 , 0
139	XM203E2, w/o liner	4.2, (616)
141	XM203E2	0 , 0
143	XM203E2 + TiO_2/wax cap	0 , 0
145	XM203E2	2.3, (328)

V. CONCLUSIONS

1. The wear-reducing liner in the XM201E2 charge does not reduce the heat input to the gun barrel.

2. The failure of the wear-reducing liner in the XM201E2 charge to exert any influence on heat transfer may be attributed to the long ignition delay with the clean-burning igniter as compared to black powder ignited charges.

3. The presence of the wear-reducing liner in the center-core ignited XM201E1, XM119E4, and XM203E2 charges resulted in the heat input being reduced from six to eleven percent. The total heat input for the XM203E2 charge was comparable to the two zone 7 charges indicating the greater efficiency of the liner in the zone 8 XM203E2 charge.

4. The heat input from the XM201E2 charge can be reduced to comparable values for the XM201E1 and XM119E4 either by shortening the ignition delay or by placing the wear-reducing liner against the chamber wall adjacent to the projectile. Such solutions by themselves would be expected to yield a wear life comparable to the XM119E4 or the XM203E2, but still less than the wear life of the M119 charge.

5. The addition of a wear-reducing liner equipped with flaps placed against the projectile base in conjunction with a shorter ignition delay and the existing liner in the XM201E2 charges reduces the heat input to a value comparable to the M119 charge. The addition of the extra liner to the XM203E2 charge substantially reduces the heat input for this charge as well. It appears that it is possible to design a zone 7 and zone 8 charge with wear rates comparable to the M119 charge.

6. The version of the XM201E2 charge containing M6 propellant had similar heat input as the center-core ignited M119 charge. Significant preheating occurred with the M15 charge. With comparable ignition delay, one would expect the M15 charge to have the same heat input as the base-ignited M6 version. No negative differential pressures were observed for the base-ignited, M6 charges with a 25mm stand-off.

7. No significant differences in heat input were observed when different projectiles were fired with the XM201E2 charge.

VI. ACKNOWLEDGMENT

The authors wish to thank the following individuals for assisting in the collection and analysis of the results presented here: Mr. A. Liberatore; Mr. V. Goetz, Mr. J. Bowen, and Dr. I. May of the Applied Ballistics Branch; and Mr. J. Evans and Mr. W. Cruickshank of the Mechanics and Structures Branch.

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APPENDIX A

BEST AVAILABLE COPY

APPENDIX A

MULTIPLE STARGAGE MEASUREMENT & INSPECTION DATA FORM

Page 1 of 3

Number	22541
Model	M185
Manufacturer	WVT. ARS.
Casting Number	X
Firing Status (Check One)	After ✓ / Before
Number of Rounds	730
Proof Officer	M. Collins [illegible]
Date of Gauging	9 Sep 1975
	155 M/M How. Tube

155 M/M Tube M185

Main Bore 39.35" to 238.05"

Gage Meas. Indicated in 1/1000 of an Inch

		Rear Face of Tube	Land Basic 6.100" Vert	Land Basic 6.100" Hor	Groove Basic 6.200 Vert	Groove Basic 6.200 Hor
		237.40	+.003	+.002	.000	.000
		236.00	.000	.000	+.002	+.00[illegible]
		235.00	-.001	0	3	[illegible]
		230.00	1	+.001	4	[illegible]
		225.00	.000	1	4	[illegible]
		220.00	0	.000	3	[illegible]
		215.00	0	-.001	4	[illegible]
		210.00	0	0	4	[illegible]
		205.00	0	0	3	[illegible]
		200.00	0	1	2	[illegible]
		195.00	-.001	1	2	[illegible]
		190.00	1	1	-.001	[illegible]
		185.00	0	1	2	-.00[illegible]
		180.00	1	0	1	+.00[illegible]
		175.00	1	1	-.002	-.00[illegible]
		170.00	-.002	1	1	[illegible]
		165.00	1	-.001	+.001	[illegible]
		160.00	0	1	1	[illegible]
		155.00	-.001	1	1	[illegible]
		150.00	2	1	3	[illegible]
		145.00	4	3	3	[illegible]
		140.00	3	2	7	[illegible]
		135.00	1	6	6	[illegible]
		130.00	6	3	4	[illegible]
		125.00	6	3	8	[illegible]
		120.00	8	6	7	[illegible]
		115.00	7	1	7	[illegible]
		110.00	10	1	7	10
		105.00	9	2	8	[illegible]
		100.00	9	10	8	9
		95.00	5	11	8	5
		90.00	7	10	7	[illegible]
		85.00	7	10	4	7
		80.00	7	7	9	[illegible]
		75.00	6	3	9	7
		70.00	3	.000	7	[illegible]
		65.00	1	+.002	8	1
		60.00	.000	3	6	1
		55.00	+.002	4	15	3
		50.00	6	5	13	8
		45.00	13	8	+.002	.000
		43.00	19	12	3	+.001
		42.35	21	13	5	1
		41.35	21	14	6	3
		40.35	22	15	16	5
		39.85	23	17	13	7
		39.60	25	21	14	7
		39.45	+.030	+.025	+.01[illegible]	+.008
			Vert	Hor		
Pullover	Meas.	39.60	6.126"	6.123	86% [illegible] Life	
					Estimated	Remaining
					Accuracy Life	
					[illegible]	
					NO BASIS	

STEAP-DS Form 106, 17 Jun 64 (Part I)

PRECEDING PAGE BLANK-NOT FILMED

APPENDIX A

155 M/M Howitzer Tube M185 — Chamber

DISTANCE (Inches) FROM					GAUGE MEASUREMENTS INDICATED IN 1/1000 OF AN INCH					
					VERTICAL			HORIZONTAL		
		REAR FACE OF TUBE ✓	BASIC DIAMETER	ZERO	GAUGE READING	ACTUAL DIAMETER	DIFFERENCE	GAUGE READING	ACTUAL DIAMETER	DIFFERENCE
———	———	36.10	6.693	6.500"	+.196	6.696	+.003	+.192	6.692	-.001
		35.50	6.693		195	.695	2	192	692	1
		35.00	6.693		195	.695	2	192	692	1
		34.00	6.693		195	.695	2	192	692	1
Triangular		32.00	6.693		194	.694	1	192	692	1
Portion at		30.00	6.693		194	.694	1	192	692	1
6:00 o'clock		28.00	6.693		194	.694	1	192	692	1
		26.00	6.693		193	.693	0	192	692	1
		24.00	6.693		193	.693	0	192	692	1
Basic	Dia.	22.00	6.693		193	.693	0	192	692	1
(VERT)		20.00	6.693		193	.693	0	192	692	1
MIN	MAX	18.00	6.693		193	.693	.000	192	692	1
6.693	6.726	16.00	6.693		196	.696		191	691	2
6.712	6.758	14.00	6.693		230	.730		191	691	2
6.747	6.790	12.00	6.693		264	.764		191	691	2
6.781	6.822	10.00	6.693		298	.798		191	691	2
6.816	6.854	8.00	6.693		332	.832		191	691	2
6.851	6.886	6.00	6.693		365	.865		192	692	1
6.886	6.918	4.00	6.693		[illegible]	[illegible]		192	692	1
6.895	6.926	3.50	6.693		414	.914		192	692	1
		3.00	6.693		194	.694	+.001	192	692	1
		2.00	6.693		194	.694	1	192	692	1
		1.50	6.693		+.194	6.694	+.001	+.192	6.692	-.001

SPECIAL MEASUREMENTS

	BASIC	ACTUAL		BASIC	ACTUAL
TOTAL LENGTH OF GUN	-----	-----	ROTATION OF TUBE AT BREECH	-----	-----
TOTAL LENGTH OF TUBE	238.05"	238.05"	MOVEMENT OF TUBE AT BREECH	-----	-----
DEPTH OF BREECH RECESS	-----	-----	NUMBER OF LANDS AND GROOVES	48	48

Borescoped: (Chamber only chrome plated) Light scratches, stains, and deposits with rust and rust pitting throughout powder chamber. Chrome lightly chipped from edge of chamber at rear of cut-out portion between 5:00 and 7:00 o'clock. Light erosion and scoring in base metal where chrome is removed. Moderate to light heat checking encircling chamber beginning 10" from rear face of tube (RFT) and continuing forward to 85" from (RFT) in the grooves and to 100" on lands. Any further heat checking is obscured by heavy coppering and other deposits. Lands are lightly flattened in the forcing cone area with the lands between 3:30 and 8:30 o'clock being more severly flattened and expanded over into grooves. This condition is more pronounced in the 6:00 o'clock area where it extends between 39.0" and 39.75" from (RFT). Moderate to light erosion encircling forcing cone and extending forward to 53" from (RFT). Lands are rounded throughout eroded area with edges of lands rounded to 90" from (RFT) and driving edges rounded to 110". Light longitudinal scoring encircling bore between forcing cone and 45" from (RFT). Light erosion and scoring on forward edges of bore evacuator holes and port holes. Light scratches, stains, carbon, coppering, and other deposits (Continued on page #3)

APG STAMPED	STARGAUGED AND INSPECTED BY D. Tesch	REVIEWED BY David A. Tesch
ROOMAN J. McWilliams	TIME	COMPILATOR
RECORDER S. Moore	PLACE 525	GRAPHED BY

155 M/M How. Tube # 22541 M185 WVT. ARS. ~~Production~~ for Mr Collins 000302-61601-2-01

9 Sept 1975 A.F. 730 Rds.

STEAP-DS Form 106, 17 Jun 64 (Part II)

Manufacturer	WVT ARS
Model	M185
Number	2254 (?)
Size	155mm How. Tube
Proof Officer	Mr. Collins
W.O.	303-61601-01
Number of Rounds	730
Firing Status (Check one)	Before: ___ After: ✓
Date of Gaging	9 Sept 1975

INSPECTION REMARKS

(PT-IOP 750-1)

(Continued from page #2)
with moderate to heavy rust and rust pitting throughout main bore. Coppering is more pronounced in grooves and between 70" and 150" from (RFT).

No photographs or impressions taken at this time.

Gaged by: D. Tesch
J. McWilliams
S. Moore

STEAP-MT Form 181, 7 Dec 71 (REPLACES STEAP-DS FORM 181, 17 JUN 64, WHICH MAY BE USED)

APPENDIX B

APPENDIX B

Firing Sequence

ID	Round Number	Charge	Projectile	Ignition delay, ms	Chamber Pressure MPa, (kpsi)	Coil Velocity, m/s, (ft/s)	Remarks
50	1	M4A1	M107 mod			557.5 (1829)	
51	2	M4A1	M107 mod			558.1 (1831)	
52	3	XM201E2 w/o liner	M107 mod	185	215 (31.2)	676.0 (2218)	
53	4	XM201E2	M107 mod	205	216 (31.4)	678.5 (2226)	
54	5	M4A2	M107 mod			562.1 (1844)	
55	6	XM201E1 w/o liner	M107 mod	88	215 (31.2)	681.2 (2235)	
56	7	XM201E1	M107 mod	106	221 (32.1)	681.8 (2237)	
57	8	M4A2	M107 mod			559.0 (1834)	
58	9	M119	M107 mod	216	188 (27.3)	659.0 (2162)	Lacing Jacket Removed
59	10	XM119E4 w/o liner	M107 mod	237	221 (32.1)	690.1 (2264)	
60	11	XM119E4	M107 mod	418	219 (31.8)	693.7 (2276)	

ID	Round Number	Charge	Projectile	Ignition delay, ms	Chamber Pressure MPa, (kpsi)	Coil Velocity, m/s, (ft/s)	Remarks
61	12	M4A2	M107 mod			562.4 (1845)	
62	13	XM201E2 w/o liner	M107 mod	175	214 (31.0)	675.7 (2217)	
63	14	XM119E4 w/o liner	M107 mod	190	225 (32.7)	690.7 (2266)	
64	15	XM201E2	M107 standard	245	214 (31.0)	677.0 (2221)	
65	16	M4A2	M107 mod			562.4 (1845)	
66	17	XM201E2	M107 mod	270	215 (31.2)	671.5 (2203)	
67	18	M4A2	M107 mod			571.2 (1874)	
68	19	XM119E4	M107 mod	238	214 (31.0)	680.3 (2232)	
69	20	M4A2	M107 mod				
70	21	XM201E2 w/o liner	M107 mod	250	215 (31.2)	674.8 (2214)	
71	22	XM201E1 w/o liner	M107 mod	142	216 (31.4)	681.8 (2237)	
72	23	XM201E2	M107 standard	200	214 (31.0)	675.1 (2215)	
73	24	M4A1	M107 mod			556.6 (1826)	
74	25	XM201E2	M107 mod	155	212 (30.8)	672.4 (2206)	

ID	Round Number	Charge	Projectile	Ignition delay, ms	Chamber Pressure MPa, (kpsi)	Coil Velocity, m/s, (ft/s)	Remarks
75	26	M4A2	M107 mod			563.9 (1850)	
76	27	XM201E1 w/o liner	M107 mod	155	220 (31.9)	681.2 (2235)	
77	28	XM201E1	M107 mod	187	223 (32.3)	681.8 (2237)	
78	29	M4A2	M107 mod			561.4 (1842)	
79	30	M119	M107 mod	116	185 (26.9)	658.7 (2161)	Lacing Jacket Removed
80	31	XM119E4 w/o liner	M107 mod	185	219 (31.8)	689.2 (2261)	
81	32	XM119E4	M107 mod	273	214 (31.0)	684.9 (2247)	
82	33	M4A2	M107 mod			559.3 (1835)	
83	34	XM201E2	M549	188	210 (30.4)	672.7 (2207)	
84	35	M4A2	M107 mod			561.4 (1842)	
85	36	XM201E2	M483A1	245	230 (33.3)	651.4 (2137)	
86	37	M4A2	M107 mod			562.4 (1845)	
87	38	XM201E2	M107 standard	280	214 (31.0)	677.6 (2223)	
88	39	XM201E2 w/o liner	M107 mod	219	219 (31.8)	676.7 (2220)	Ablator, muzzle flash

ID	Round Number	Charge	Projectile	Ignition delay, ms	Chamber Pressure MPa, (kpsi)	Coil Velocity, m/s, (ft/s)	Remarks
89	40	XM201E2 w/o liner	M107 mod	224	224 (32.5)	680.6 (2233)	Ablator, muzzle flash
91	41	XM201E2 w/o liner	M107 mod	86	211 (30.6)	674.2 (2212)	BP igniter from M4A1
92	42	XM201E2 w/o liner	M107 mod	78	208 (30.2)	671.5 (2203)	BP igniter from M4A1
93	43	M4A1	M107 mod			558.7 (1833)	
94	44	XM201E2	M107 mod	70	214 (31.0)	668.1 (2192)	BP igniter from M4A1
95	45	M4A2	M107 mod			560.5 (1839)	
96	46	XM201E1	M107 mod	142	220 (31.9)	677.9 (2224)	
97	47	M4A2	M107 mod			560.2 (1838)	
98	48	M119	M107 mod	180	190 (27.5)	661.7 (2171)	Lacing Jacket Removed
99	49	M119	M107 standard		187 (27.1)	666.3 (2186)	Lacing Jacket Removed
99A	50	M119	M107 standard		187 (27.1)	666.0 (2185)	Lacing Jacket Removed
101	51	XM201E2	M107 mod	80	214 (31.0)	671.2 (2202)	BP igniter from M4A1

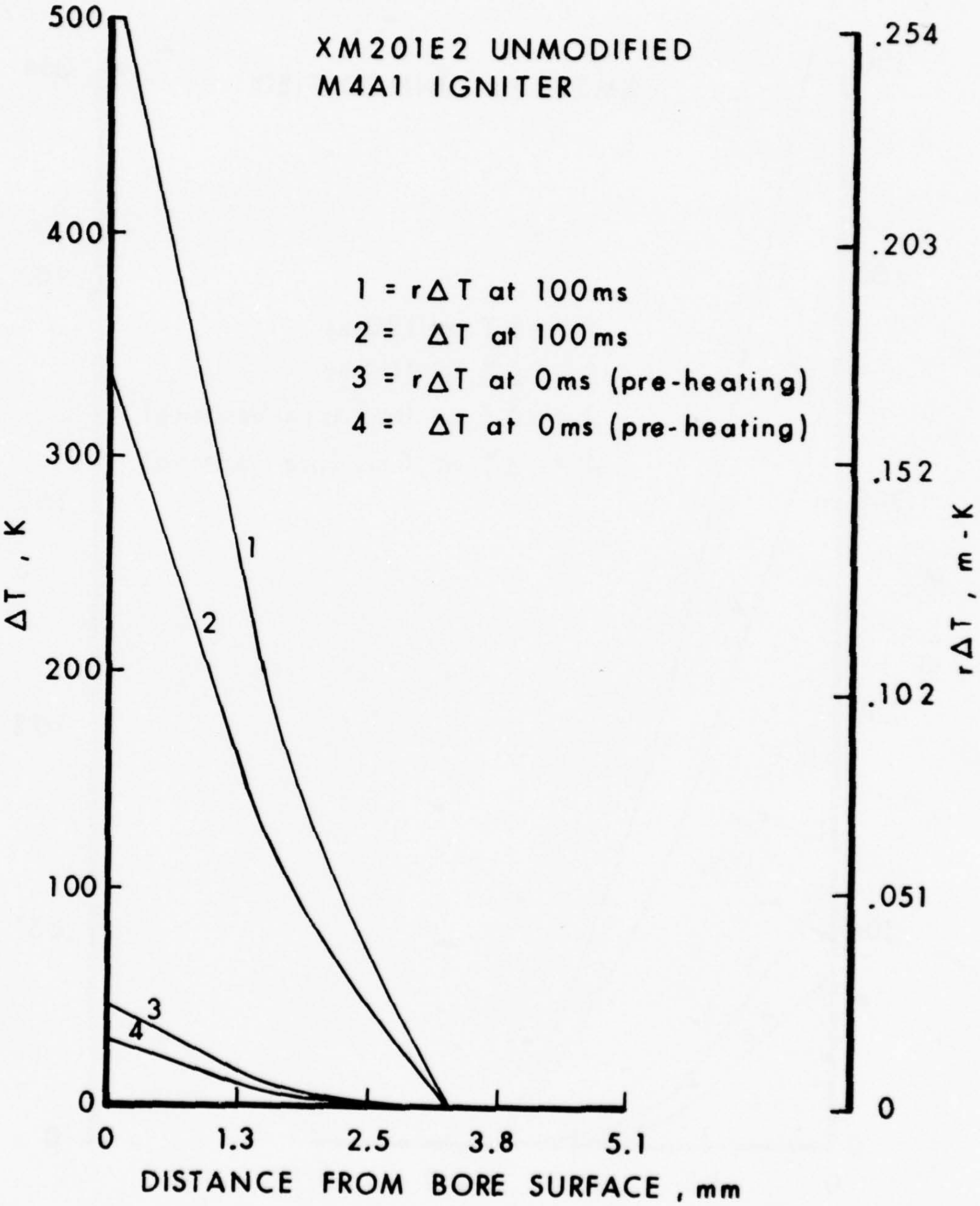
ID	Round Number	Charge	Projectile	Ignition delay, ms	Chamber Pressure MPa, (kpsi)	Coil Velocity, m/s, (ft/s)	Remarks
102	52	M4A2	M107 mod			560.2 (1838)	
103	53	XM201E2	M549	277	214 (31.0)	674.5 (2213)	
104	54	M4A2				559.6 (1836)	
105	55	XM201E2	M483A1	158	227 (32.9)	652.0 (2139)	
106	56	M4A2	M107 mod			560.5 (1839)	
107	57	XM201E2 w/o liner	M107 mod	320	216 (31.4)	670.9 (2201)	TiO_2/wax cap
108	58	M4A2	M107 mod			563.3 (1848)	
109	59	XM201E2 w/o liner	M107 mod	320	214 (31.0)	671.2 (2202)	TiO_2/wax cap
110	60	M4A2	M107 mod			563.0 (1847)	
111	61	M4A2	M107 mod			559.6 (1836)	
112	62	M6 in XM201E2	M107 mod	250	213 (30.9)	688.8 (2260)	
113	63	M15 in XM201E2	M107 mod	360	230 (33.3)	694.0 (2277)	
114	64	XM201E2 (flaps)	M107 mod	300	212 (30.7)	671.5 (2203)	
115	65	M4A2	M107 mod			560.2 (1838)	
116	66	M6 mod	M107 mod	240	214 (31.1)	686.7 (2253)	

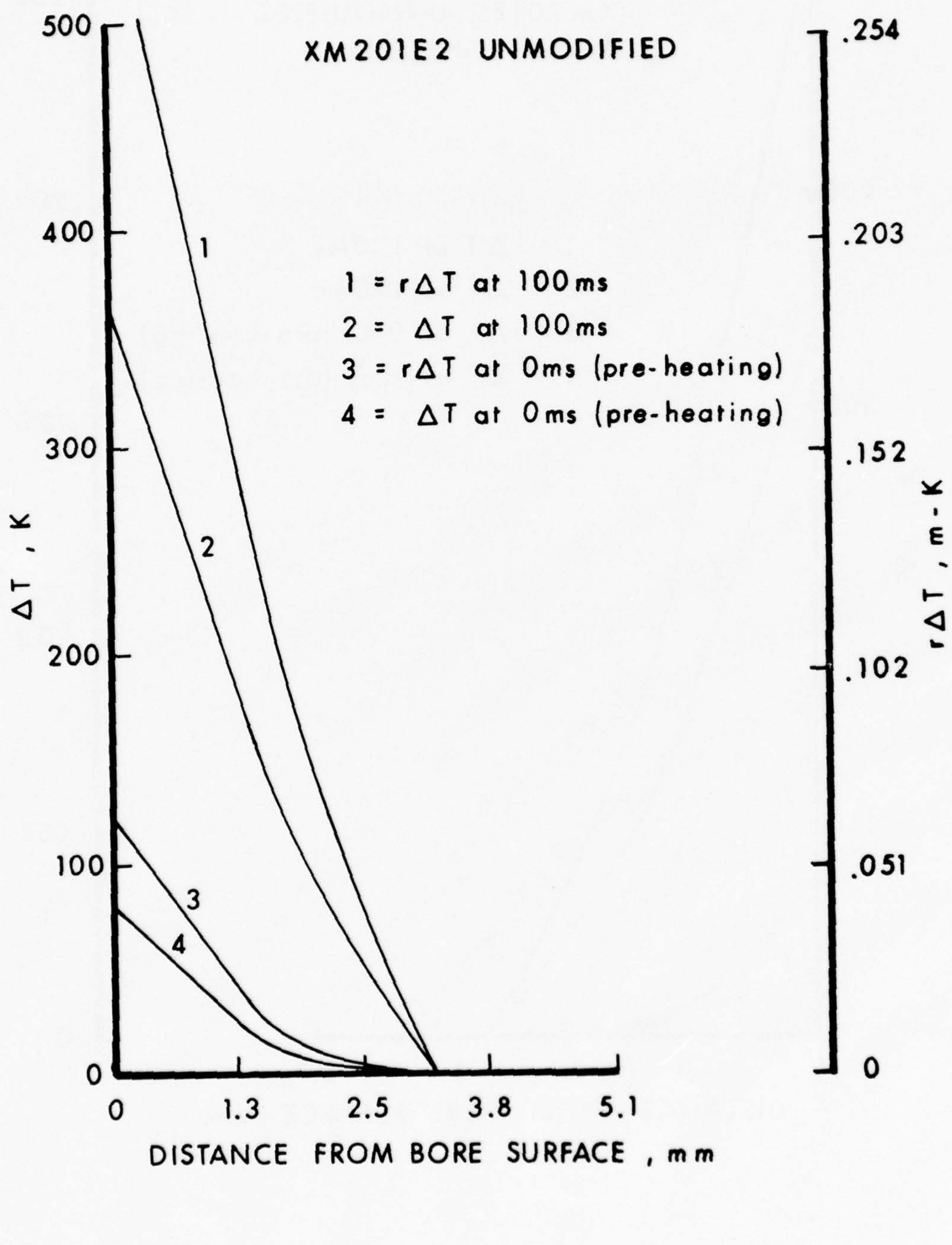
ID	Round Number	Charge	Projectile	Ignition delay, ms	Chamber Pressure MPa, (kpsi)	Coil Velocity, m/s, (ft/s)	Remarks
117	67	M15 mod	M107 mod	402	226 (32.8)	694.6 (2279)	
118	68	XM201E2 (flaps)	M107 mod	172	219 (31.8)	672.7 (2207)	
119	69	M4A2	M107 mod			561.4 (1842)	
120	70	M6 mod	M107 mod	220	212 (30.7)	686.4 (2252)	
121	71	M15 mod	M107 mod	275	230 (33.3)	694.3 (2278)	
122	72	XM201E2 (flaps)	M107 mod	205	213 (30.9)	670.3 (2199)	
125	73	M4A2	M107 mod			560.5 (1839)	
128	74	XM201E2 (flaps)	M107 mod	110	209 (30.3)	666.0 (2185)	BP igniter from M4A1
129	75	M4A2	M107 mod			561.1 (1841)	
130	76	XM201E2 (flaps)	M107 mod	88	213 (30.9)	667.2 (2189)	BP igniter from M4A1
131	77	M4A2	M107 mod			558.4 (1832)	
132	78	XM201E2	M107 mod	100	208 (30.2)	665.7 (2184)	BP igniter from M4A1; TiO_2/wax cap
133	79	M4A2	M107 mod			559.9 (1837)	
134	80	XM201E2	M107 mod	118	204 (29.6)	663.5 (2177)	BP igniter; TiO_2/wax cap

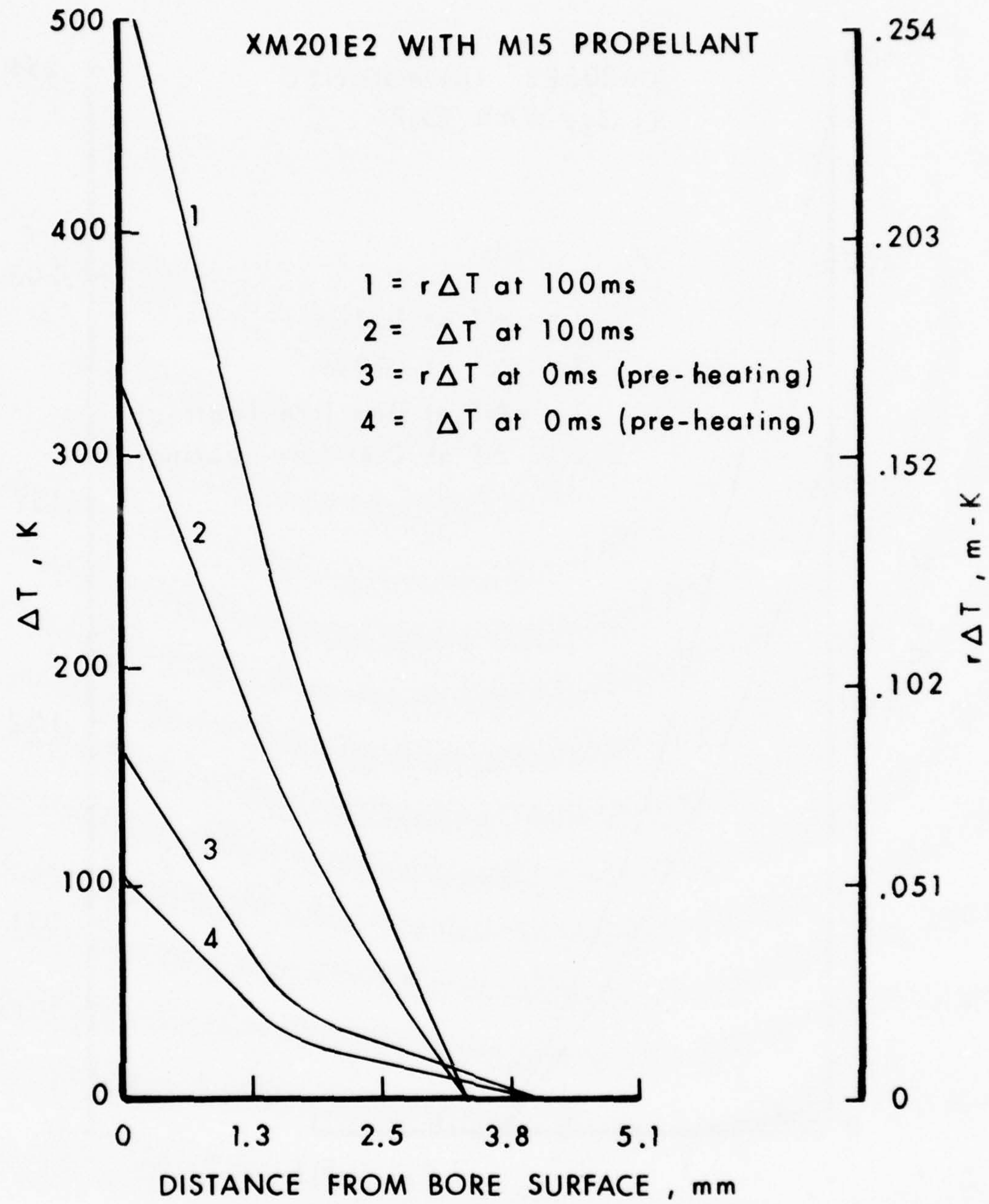
ID	Round Number	Charge	Projectile	Ignition delay, ms	Chamber Pressure MPa, (kpsi)	Coil Velocity, m/s, (ft/s)	Remarks
135	81	M4A2	M107 mod			559.6 (1836)	
136	82	M4A2	M107 mod			561.4 (1842)	
137	83	XM203E2	M107 mod	78	310 (45.0)	817.8 (2683)	
138	84	M4A2	M107 mod			562.1 (1844)	
139	85	XM203E2 w/o liner	M107 mod	108	301 (43.6)	820.5 (2692)	
140	86	M4A1	M107 mod			560.5 (1839)	
141	87	XM203E2	M107 mod	85	309 (44.8)	819.6 (2689)	
142	88	M4A1	M107 mod			557.5 (1829)	
143	89	XM203E2	M107 mod	45	309 (44.8)	817.2 (2681)	TiO_2/wax cap
144	90	M4A1	M107 mod			560.2 (1838)	
145	91	XM203E2	M107 mod	90	310 (45.0)	820.2 (2691)	
146	92	M4A1	M107 mod				
147	93	M15 mod	M107 mod	692	228 (33.0)	693.7 (2276)	2.5cm stand-off
148	94	M6 mod	M107 mod	166	216 (31.3)	692.8 (2273)	2.5cm stand-off
149	95	M15 mod	M107 mod	472	235 (34.1)	670.0 (2295)	2.5cm stand-off
150	96	M6 mod	M107 mod	120	223 (32.4)	695.9 (2283)	2.5cm stand-off

ID	Round Number	Charge	Projectile	Ignition delay, ms	Chamber Pressure MPa, (kpsi)	Coil Velocity, m/s, (ft/s)	Remarks
151	97	XM201E2	M107 mod	200	219 (31.8)	673.6 (2210)	2.5cm stand-off
152	98	M4A1	M107 mod				
153	99	XM201E2	M107 mod	212	212 (30.7)	670.6 (2200)	2.5cm stand-off

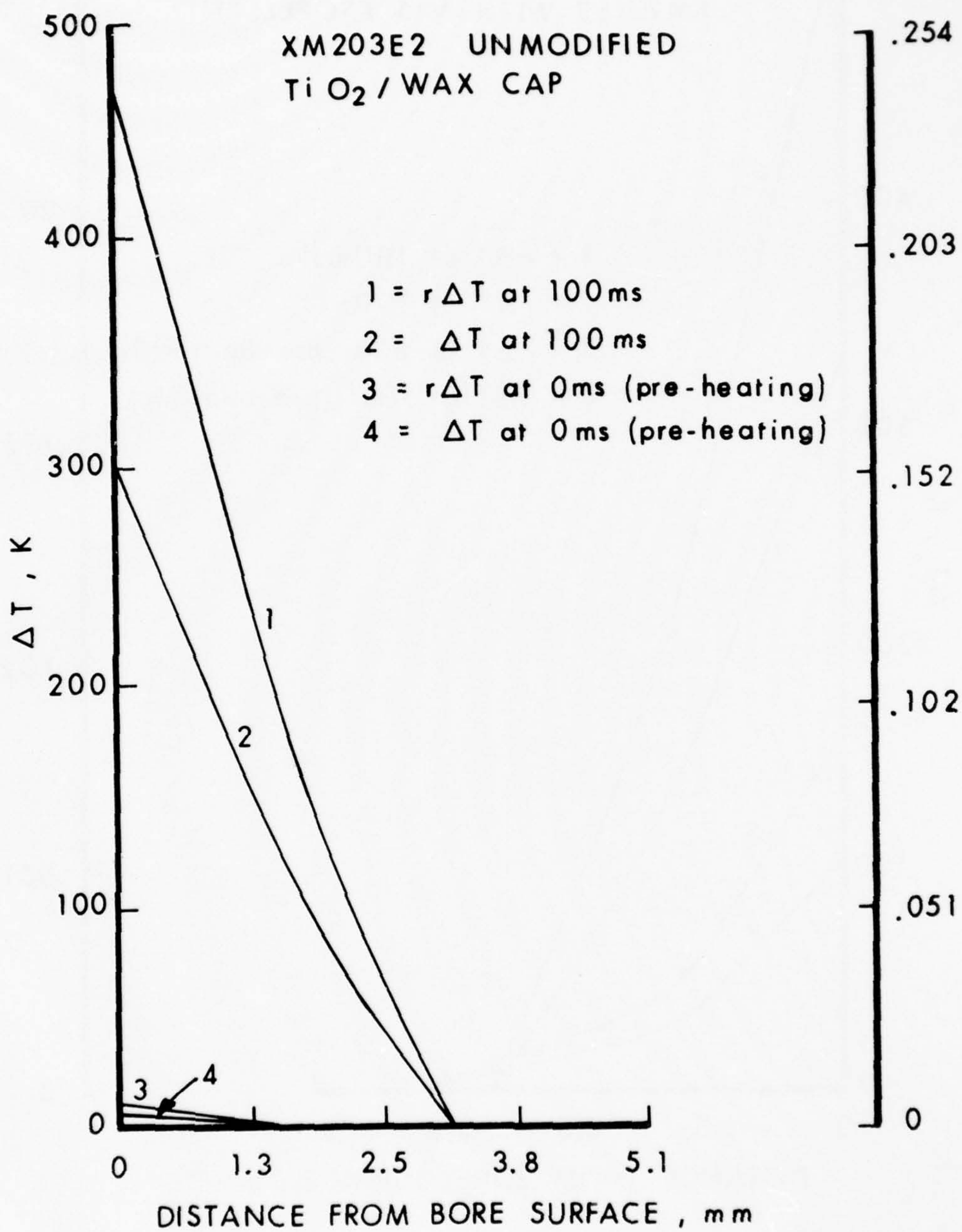
APPENDIX C

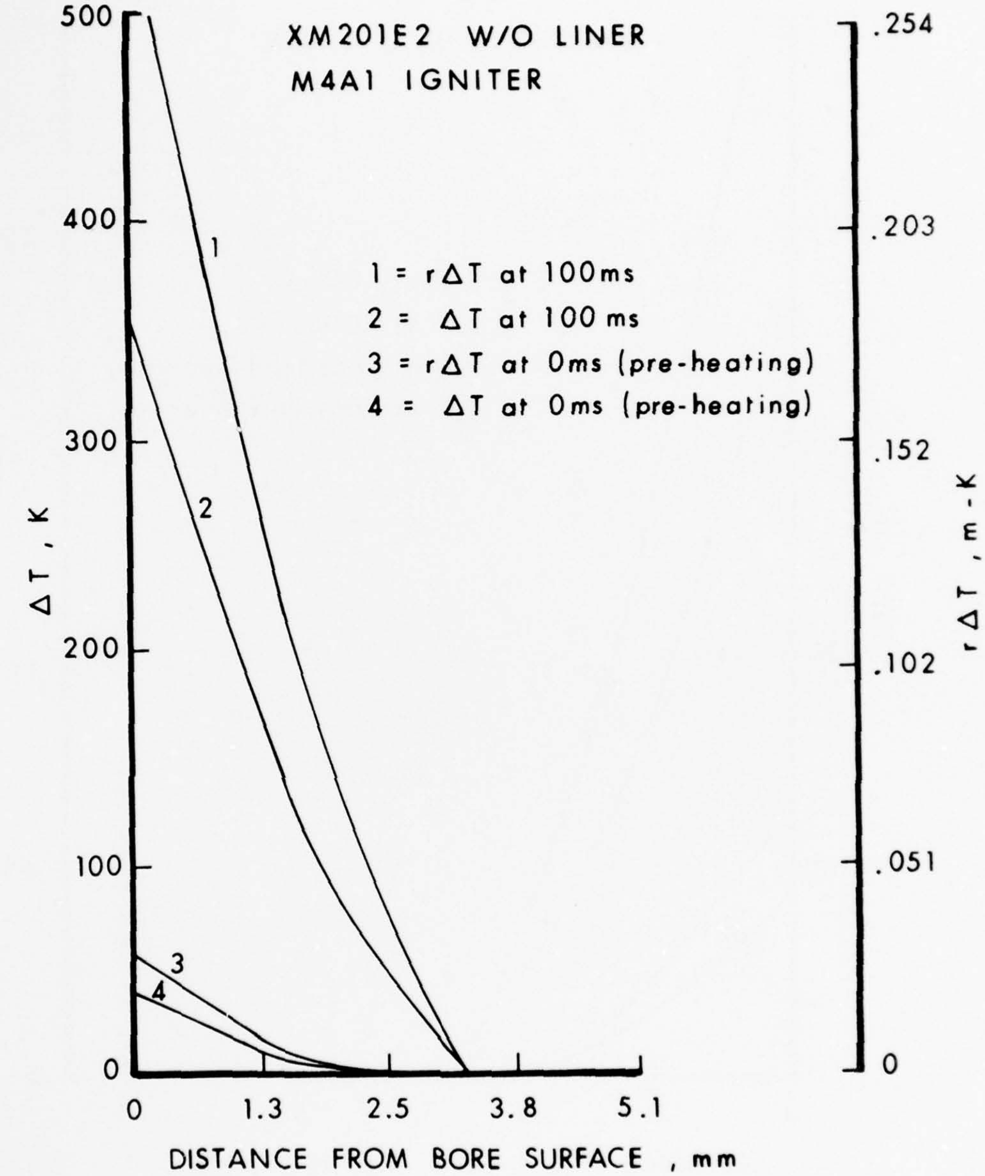

XM201E2 UNMODIFIED
M4A1 IGNITER
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
ΔT , K
rΔT , m-K
500
400
300
200
100
0
.254
.203
.152
.102
.051
0
1
2
3
4
0
1.3
2.5
3.8
5.1
DISTANCE FROM BORE SURFACE , mm

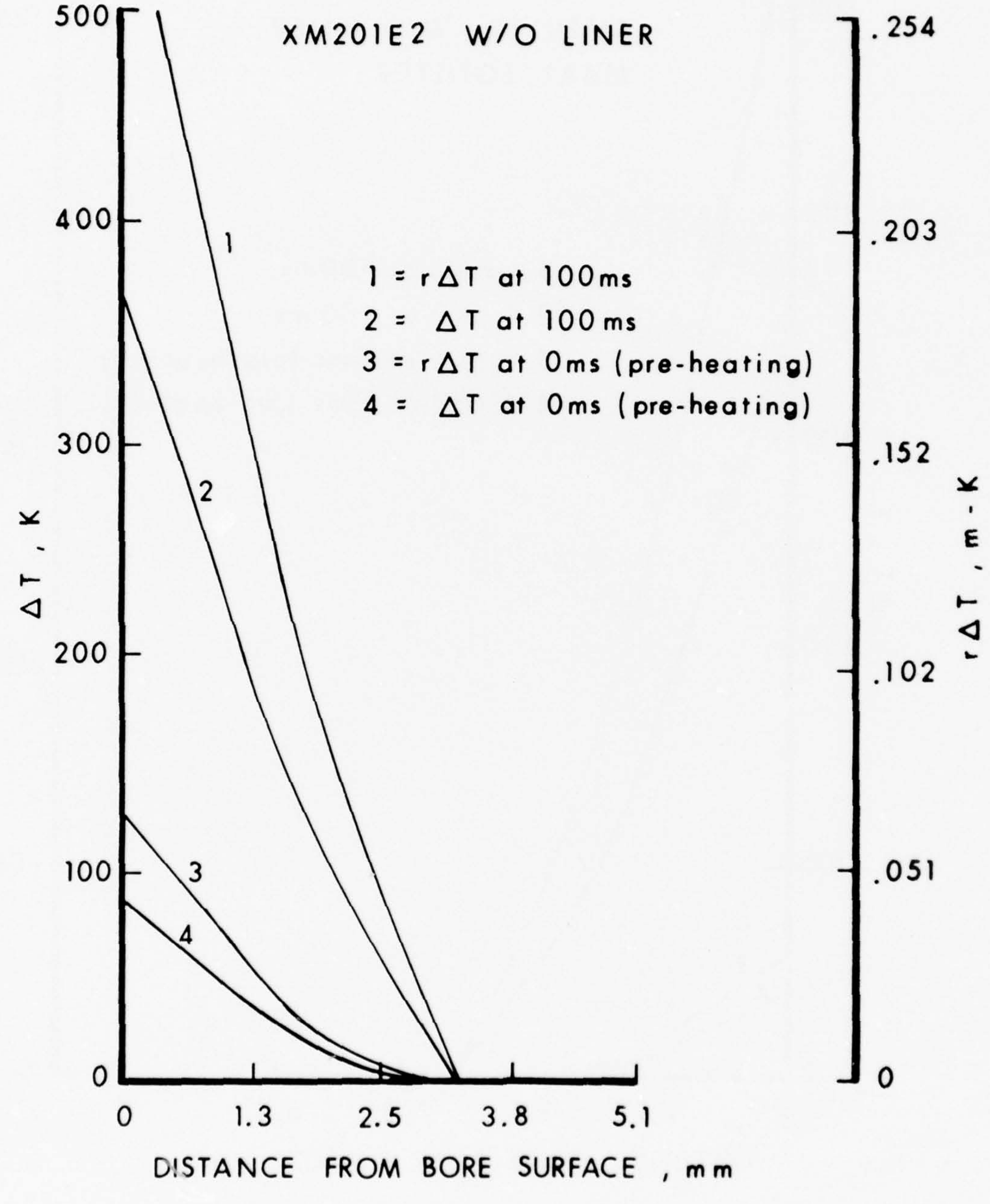

XM201E2 UNMODIFIED
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
ΔT , K
rΔT , m-K
500
400
300
200
100
0
.254
.203
.152
.102
.051
0
0
1.3
2.5
3.8
5.1
1
2
3
4
DISTANCE FROM BORE SURFACE , mm

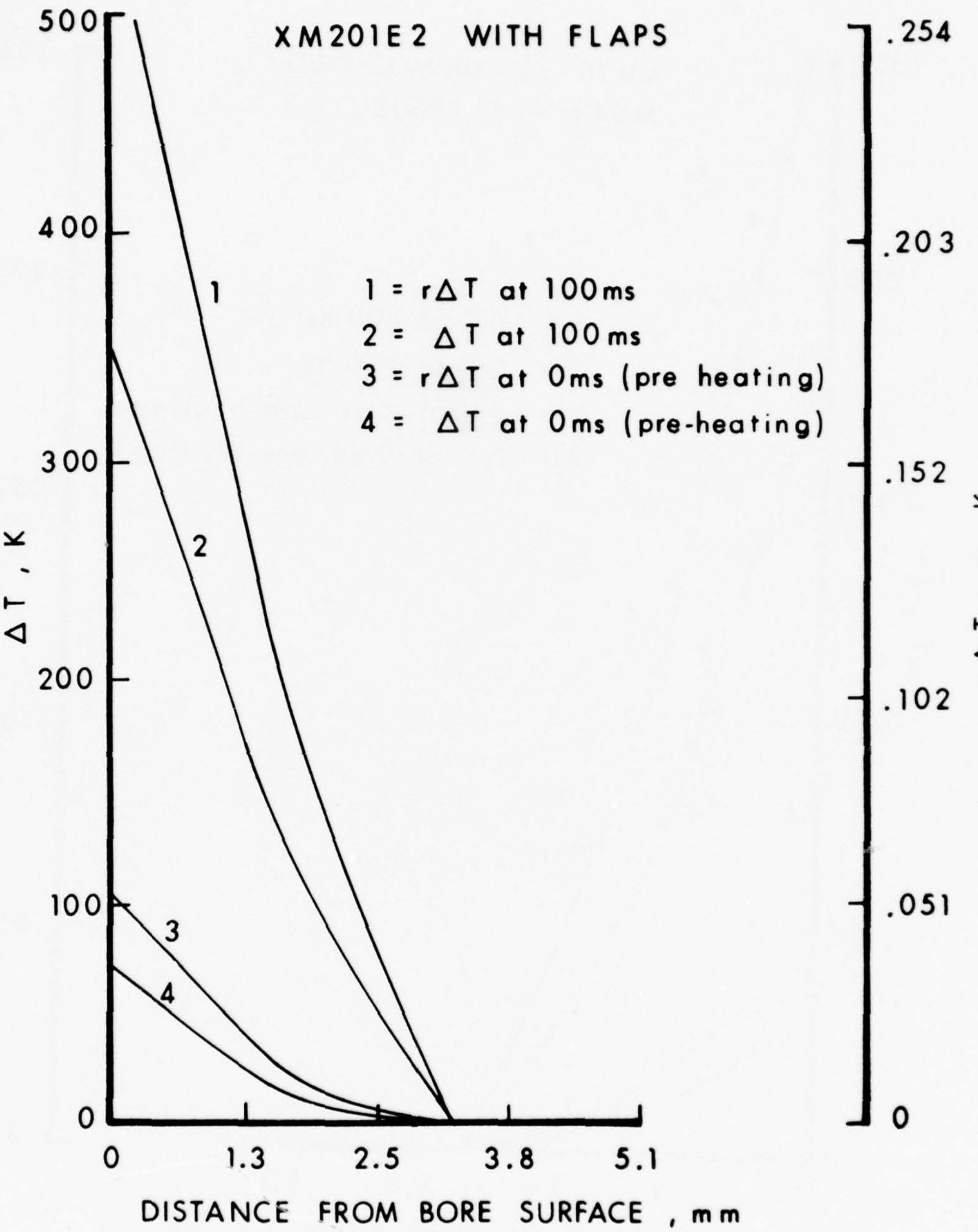


XM201E2 WITH M15 PROPELLANT
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
ΔT , K
rΔT , m-K
500
400
300
200
100
0
.254
.203
.152
.102
.051
0
1.3
2.5
3.8
5.1
DISTANCE FROM BORE SURFACE , mm
1
2
3
4

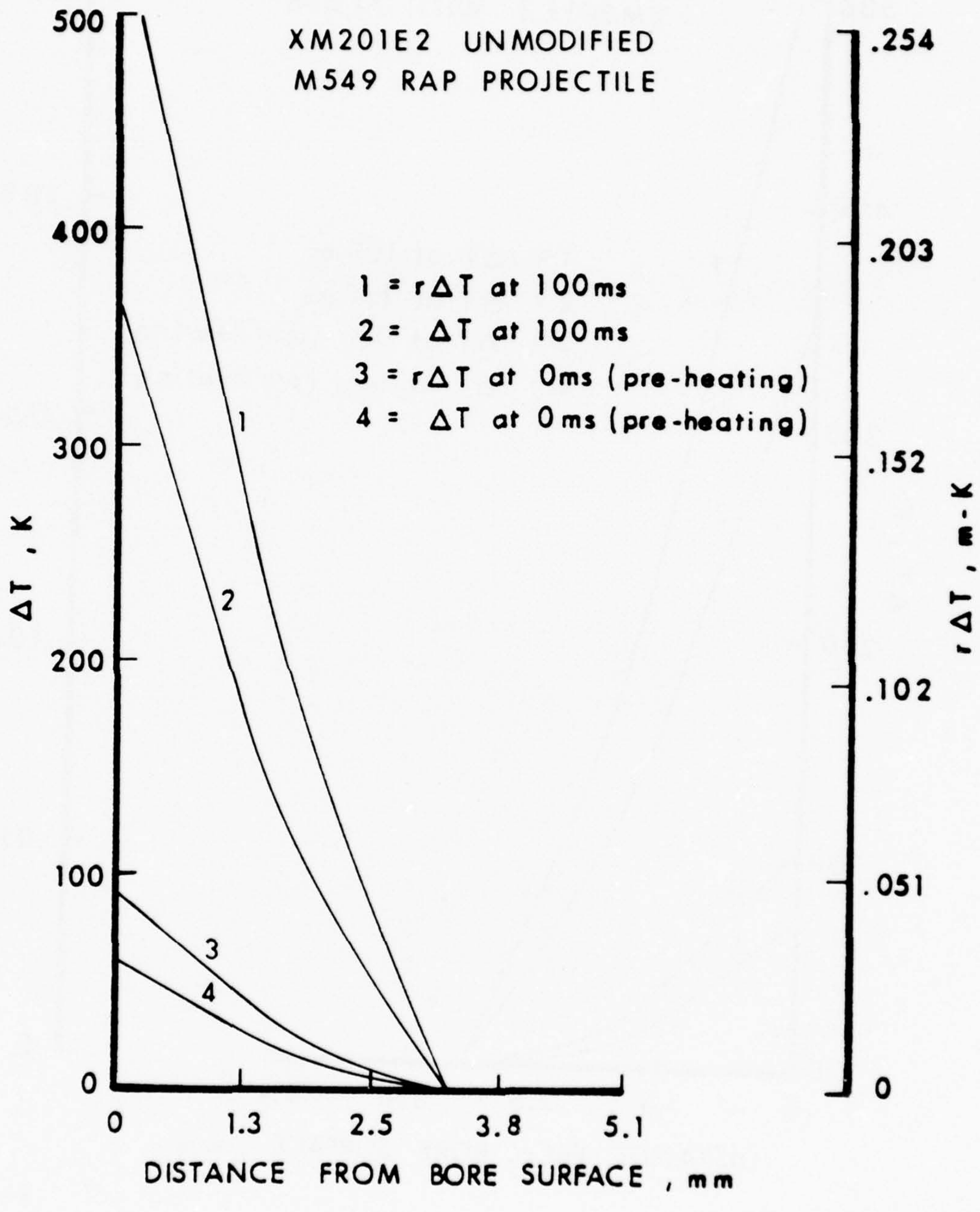

XM203E2 UNMODIFIED
Ti O2 / WAX CAP
1 = r ΔT at 100ms
2 = ΔT at 100 ms
3 = r ΔT at 0ms (pre-heating)
4 = ΔT at 0 ms (pre-heating)
500
400
300
200
100
0
ΔT , K
.254
.203
.152
.102
.051
0
r ΔT , m - K
0
1.3
2.5
3.8
5.1
DISTANCE FROM BORE SURFACE , mm
1
2
3
4

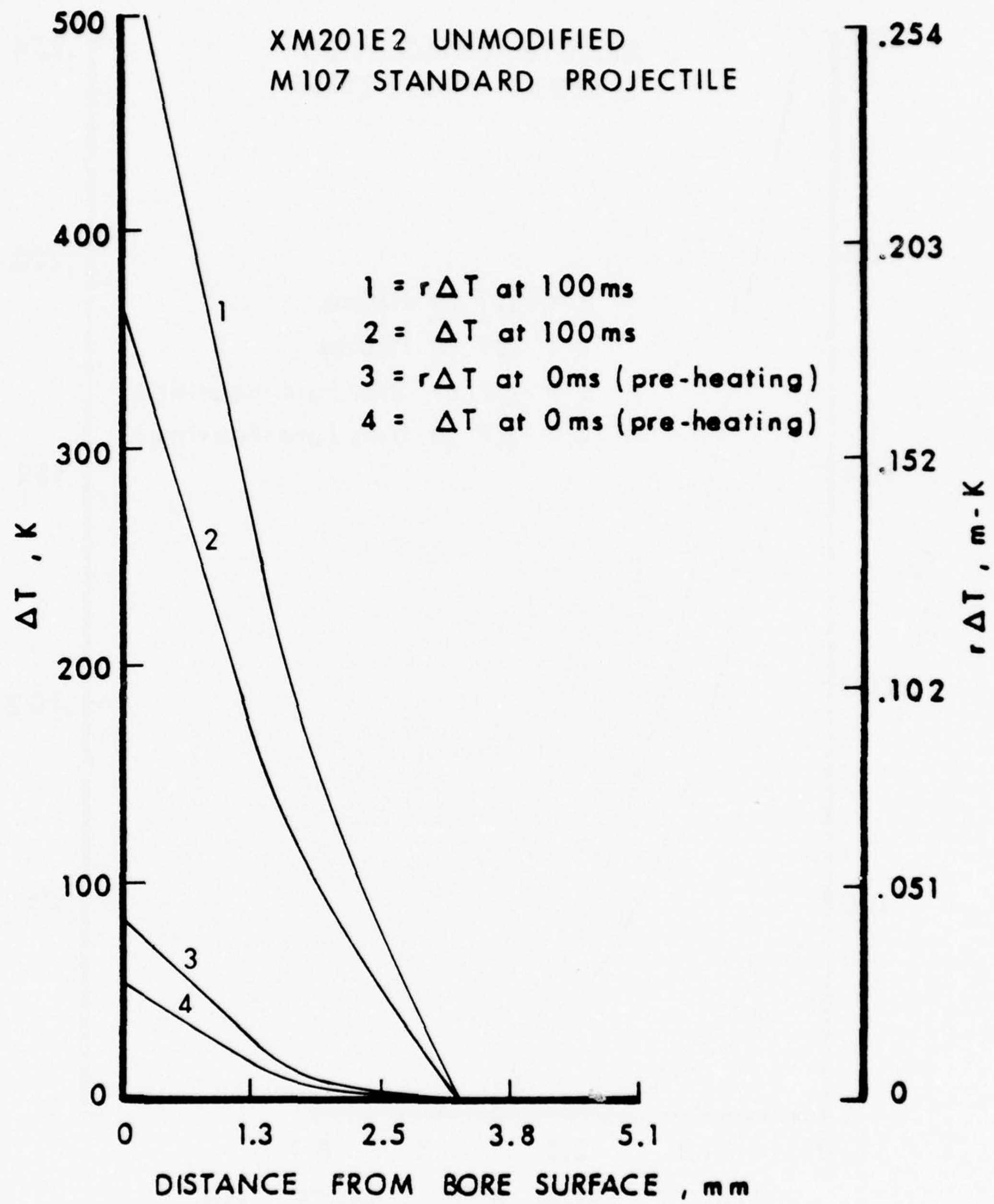

XM201E2 W/O LINER
M4A1 IGNITER
1 = rΔT at 100ms
2 = ΔT at 100 ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
ΔT , K
rΔT , m-K
500
400
300
200
100
0
.254
.203
.152
.102
.051
0
1.3
2.5
3.8
5.1
DISTANCE FROM BORE SURFACE , mm
1
2
3
4

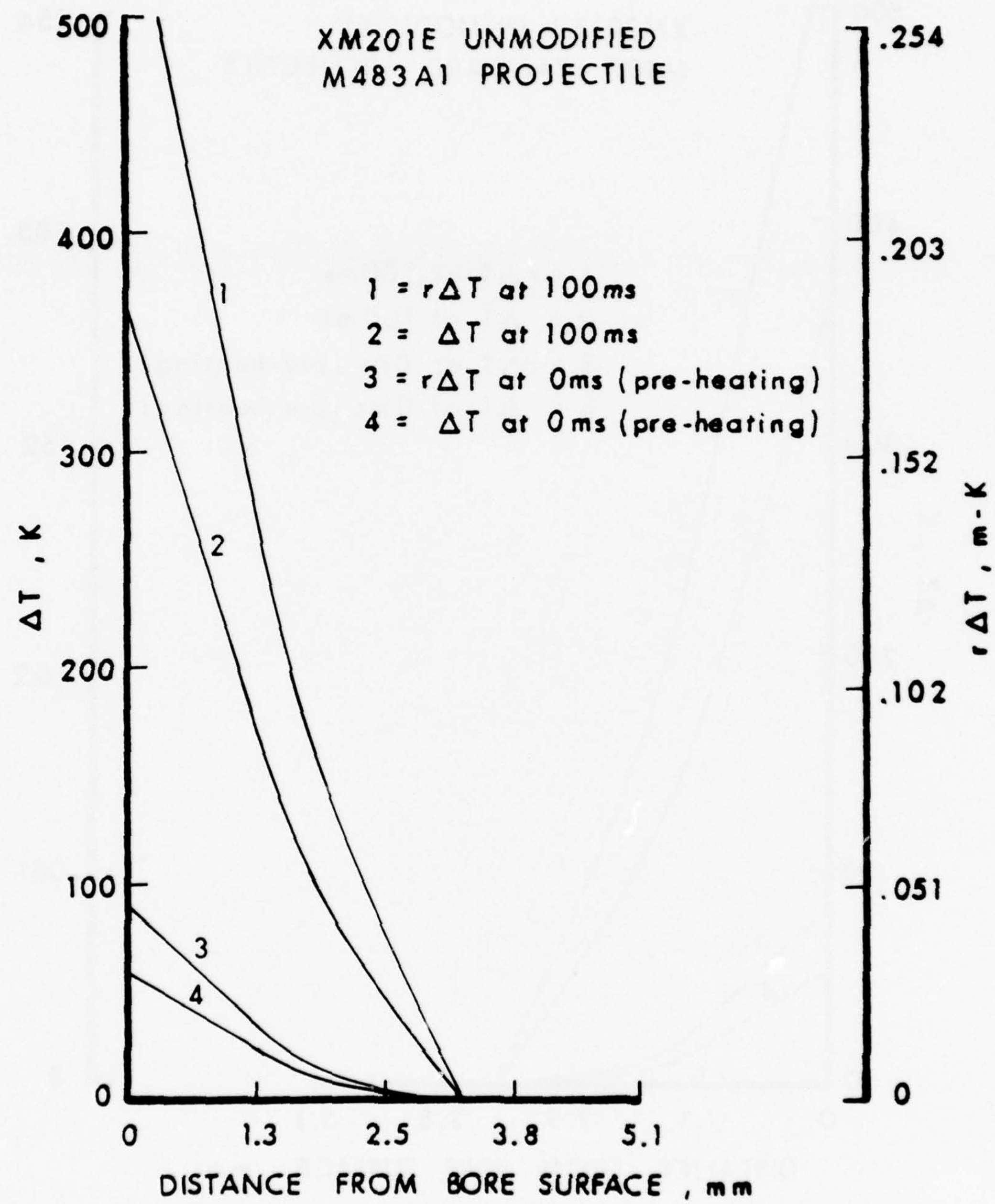

XM201E2 W/O LINER
1 = rΔT at 100ms
2 = ΔT at 100 ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
ΔT , K
rΔT , m-K
500
400
300
200
100
0
.254
.203
.152
.102
.051
0
1
2
3
4
0
1.3
2.5
3.8
5.1
DISTANCE FROM BORE SURFACE , mm



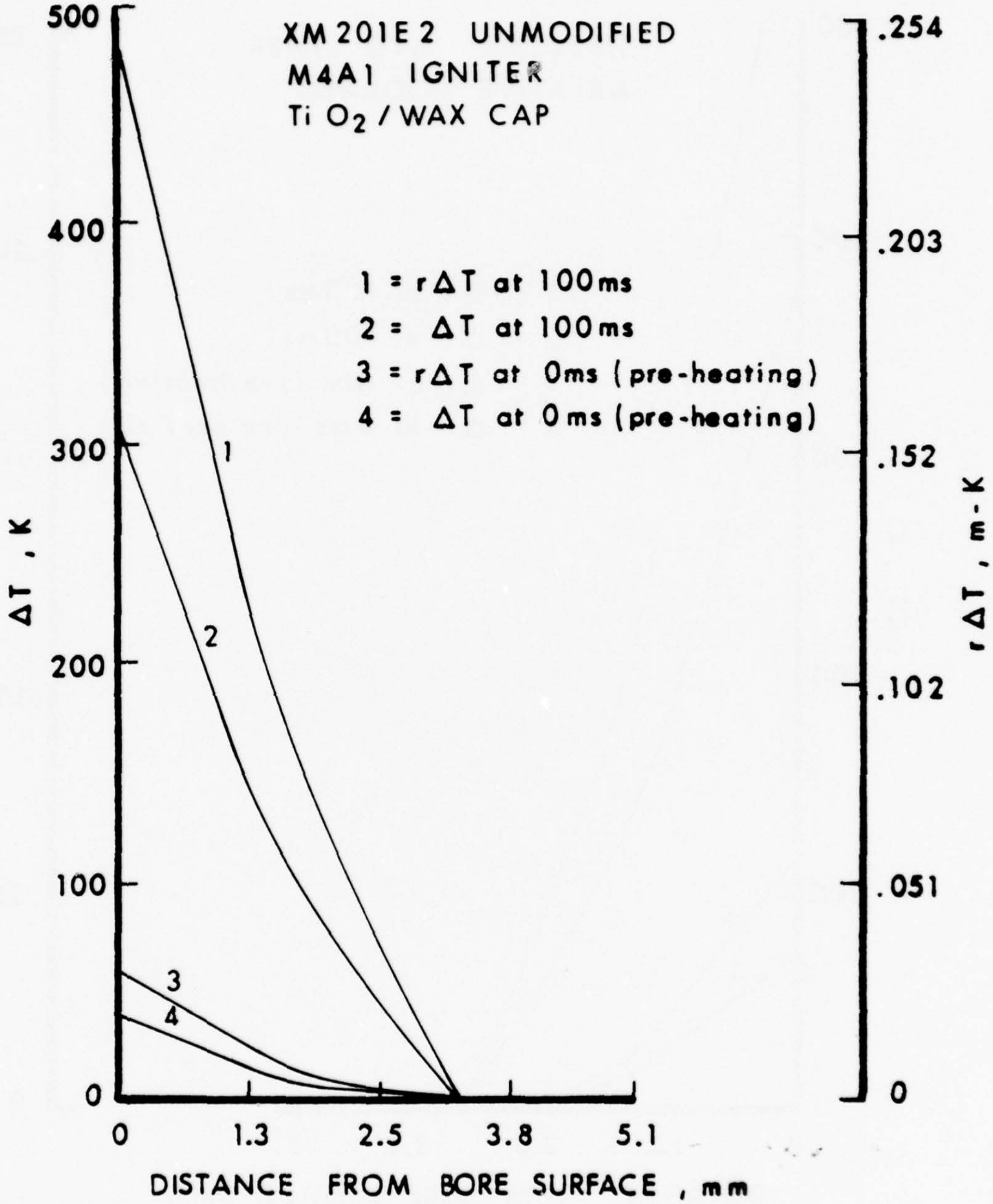
XM201E2 WITH FLAPS
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre heating)
4 = ΔT at 0ms (pre-heating)
1
2
3
4
500
400
300
200
100
0
ΔT, K
.254
.203
.152
.102
.051
0
rΔT, m-K
0
1.3
2.5
3.8
5.1
DISTANCE FROM BORE SURFACE, mm


XM201E2 UNMODIFIED
M549 RAP PROJECTILE
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
500
400
300
200
100
0
ΔT, K
.254
.203
.152
.102
.051
0
rΔT, m-K
0
1.3
2.5
3.8
5.1
DISTANCE FROM BORE SURFACE, mm
1
2
3
4

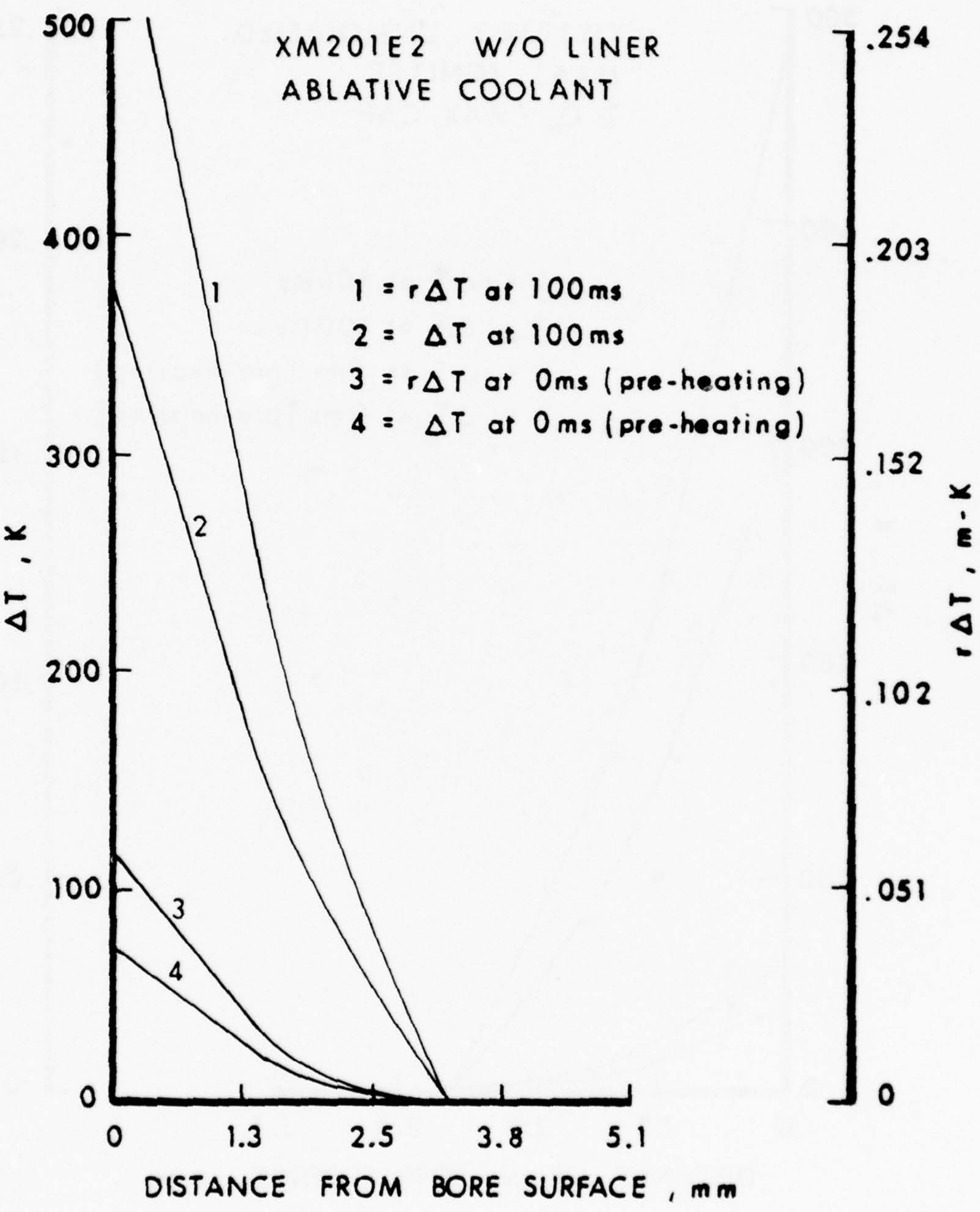

XM201E2 UNMODIFIED
M107 STANDARD PROJECTILE
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
ΔT, K
rΔT, m-K
500
400
300
200
100
0
.254
.203
.152
.102
.051
0
1
2
3
4
0
1.3
2.5
3.8
5.1
DISTANCE FROM BORE SURFACE, mm



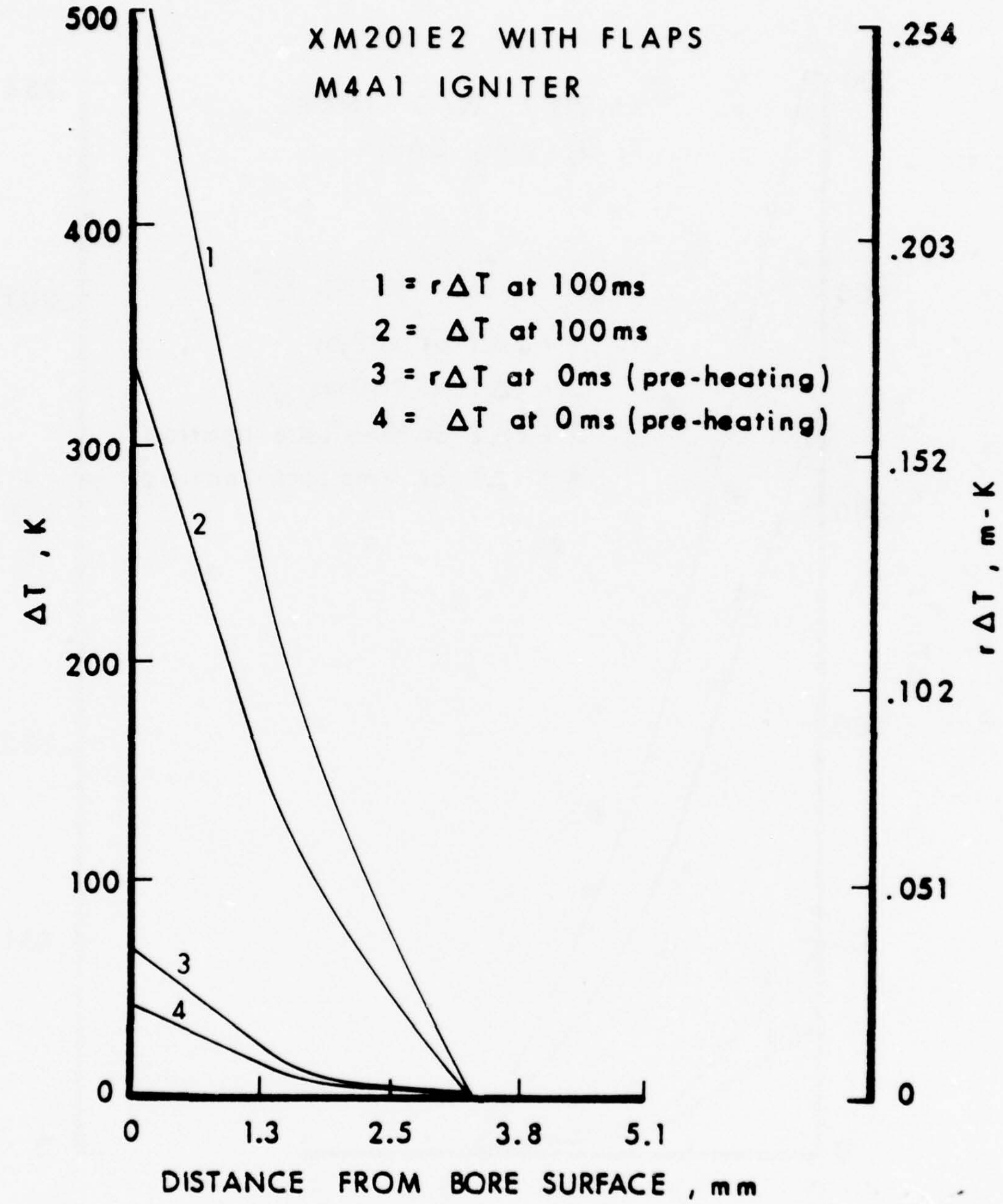
XM201E UNMODIFIED
M483A1 PROJECTILE
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
ΔT , K
rΔT , m-K
DISTANCE FROM BORE SURFACE , mm
500
400
300
200
100
0
.254
.203
.152
.102
.051
0
1.3
2.5
3.8
5.1
1
2
3
4

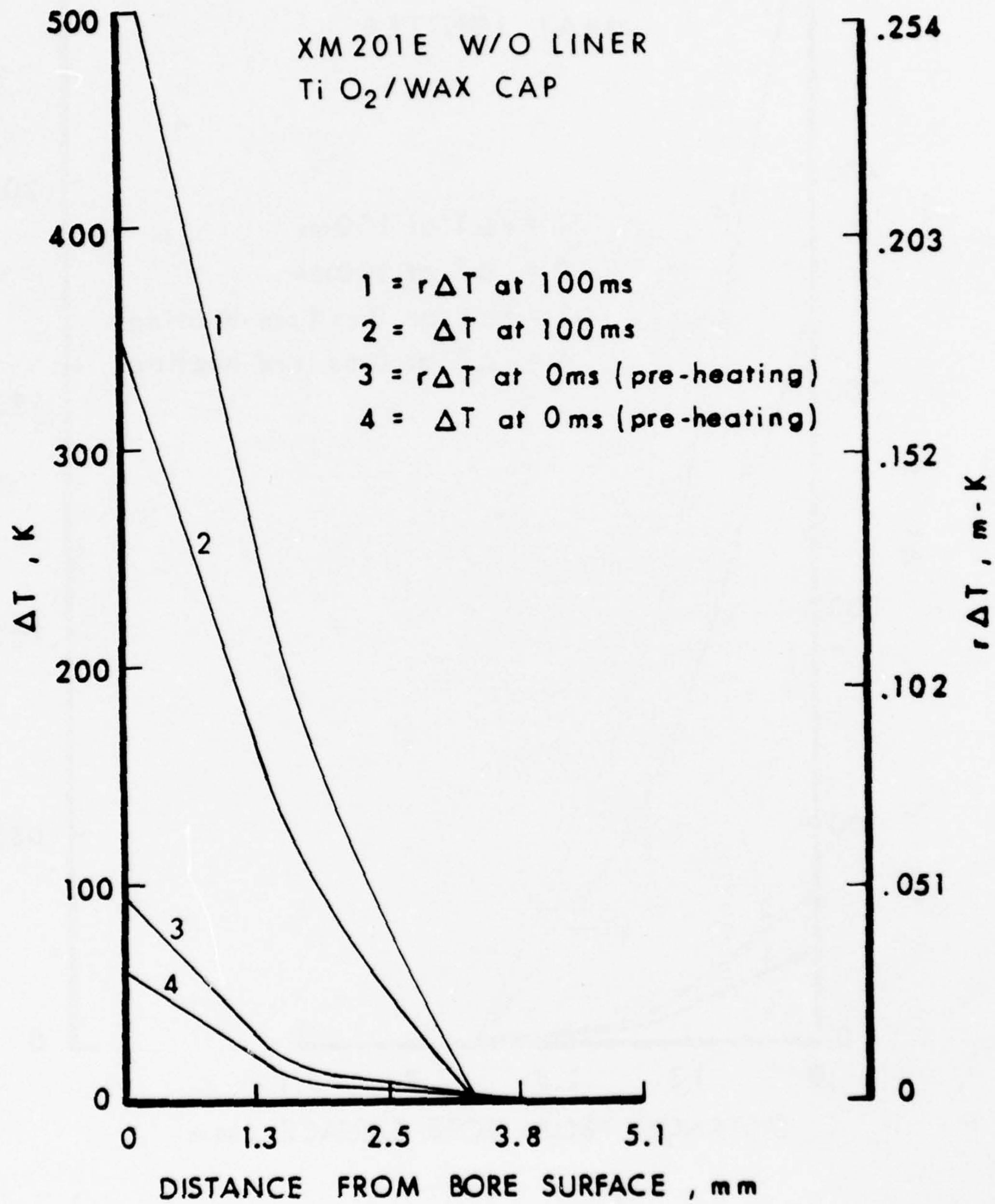


XM 201E2 UNMODIFIED
M4A1 IGNITER
Ti O2 / WAX CAP
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
ΔT , K
rΔT , m-K
500
400
300
200
100
0
.254
.203
.152
.102
.051
0
1.3
2.5
3.8
5.1
DISTANCE FROM BORE SURFACE , mm

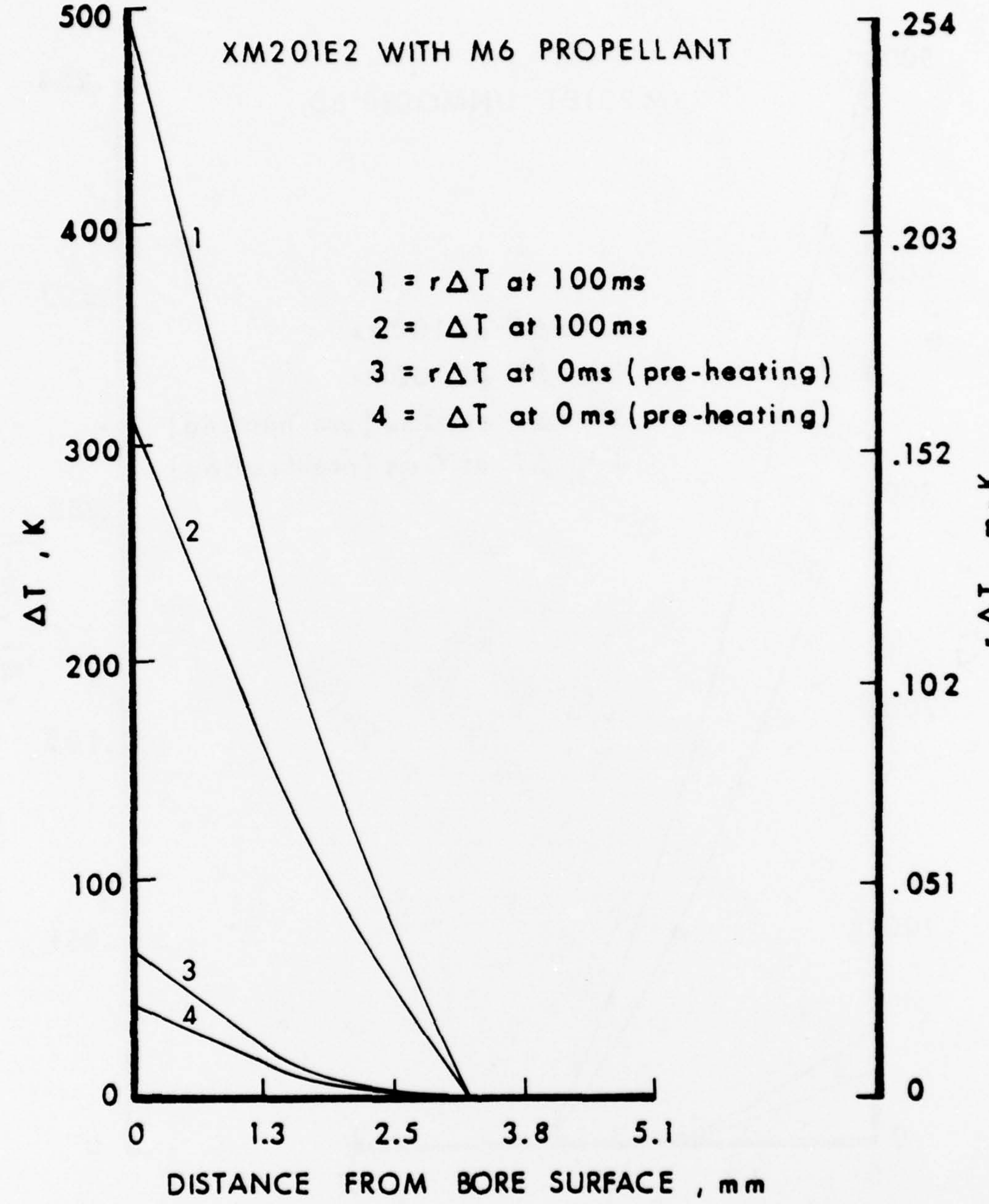


XM201E2 W/O LINER
ABLATIVE COOLANT
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
1
2
3
4
500
400
300
200
100
0
ΔT , K
.254
.203
.152
.102
.051
0
rΔT , m-K
0
1.3
2.5
3.8
5.1
DISTANCE FROM BORE SURFACE , mm

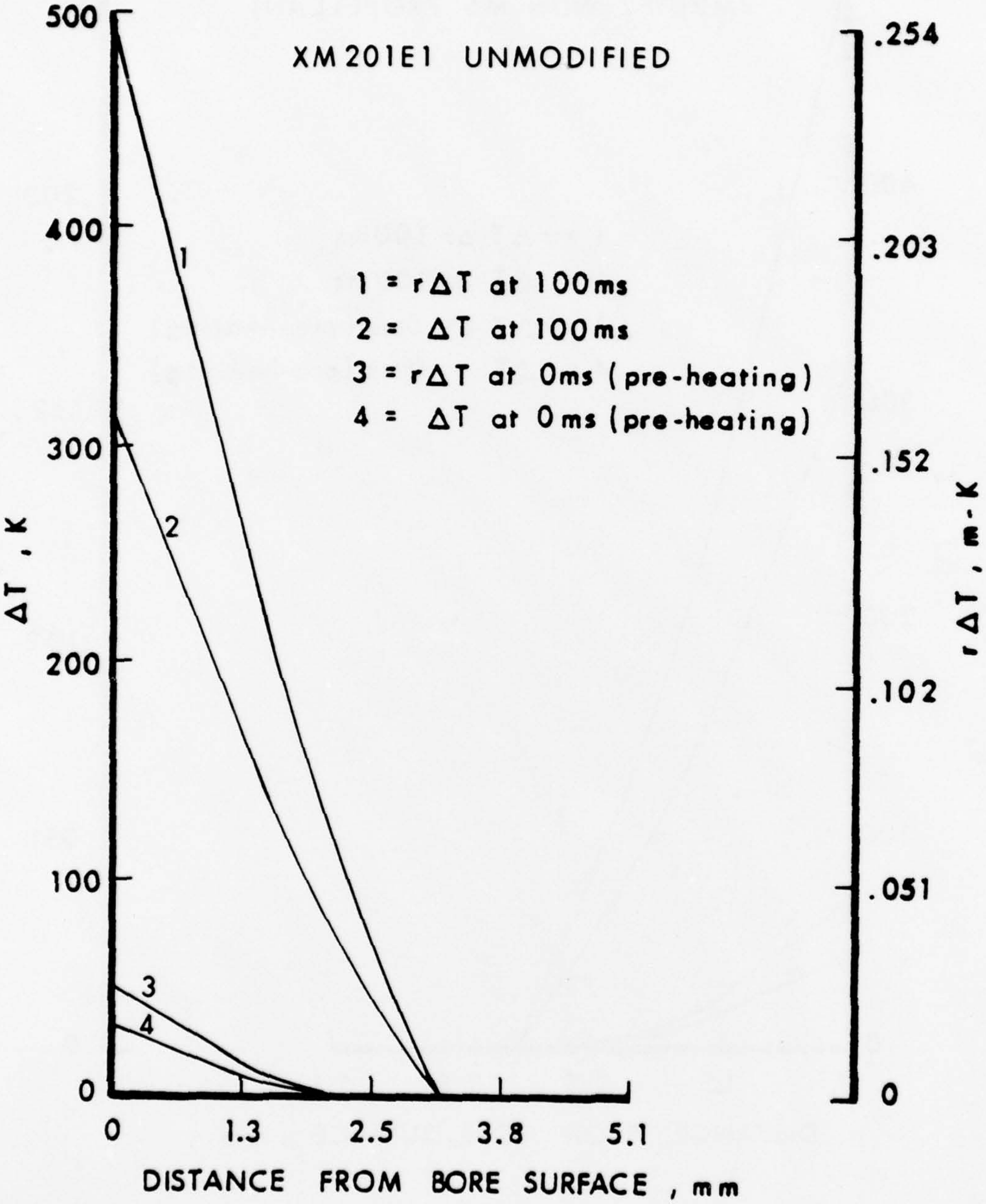

XM201E2 WITH FLAPS
M4A1 IGNITER
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
ΔT , K
rΔT , m-K
500
400
300
200
100
0
.254
.203
.152
.102
.051
0
1
2
3
4
1.3
2.5
3.8
5.1
DISTANCE FROM BORE SURFACE , mm

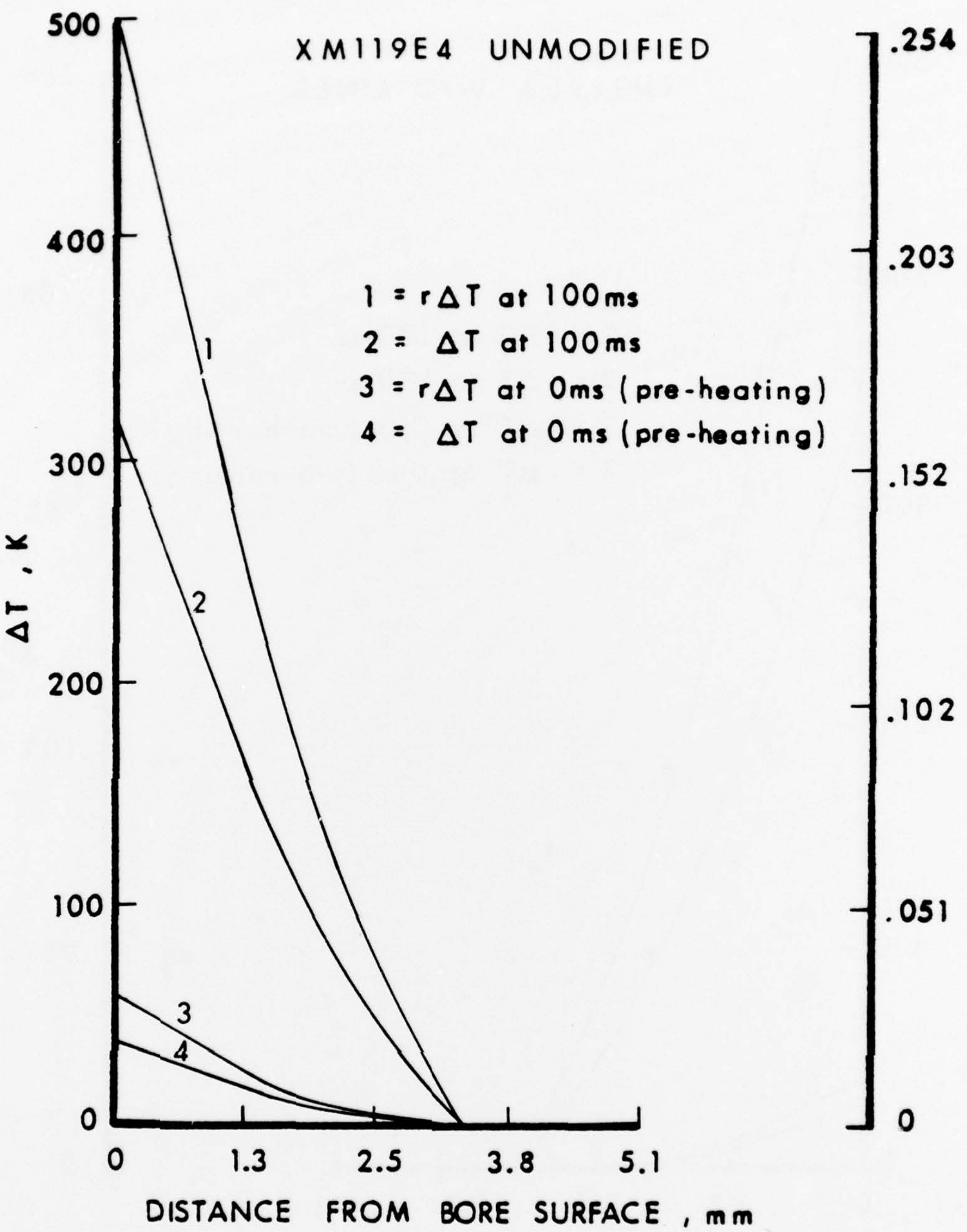


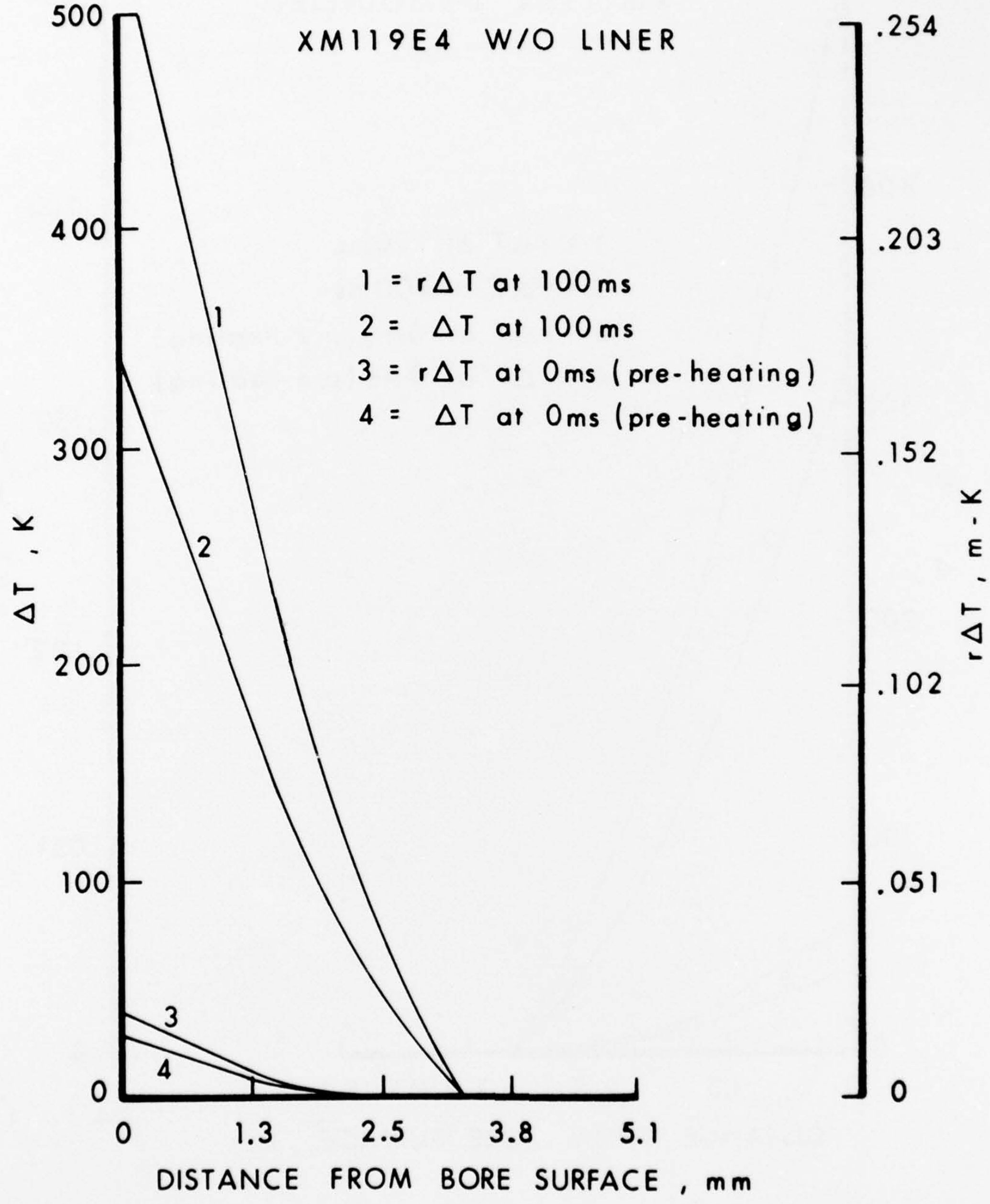
XM201E W/O LINER
Ti O_2/WAX CAP
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
1
2
3
4
500
400
300
200
100
0
ΔT , K
.254
.203
.152
.102
.051
0
r ΔT , m-K
0
1.3
2.5
3.8
5.1
DISTANCE FROM BORE SURFACE , mm

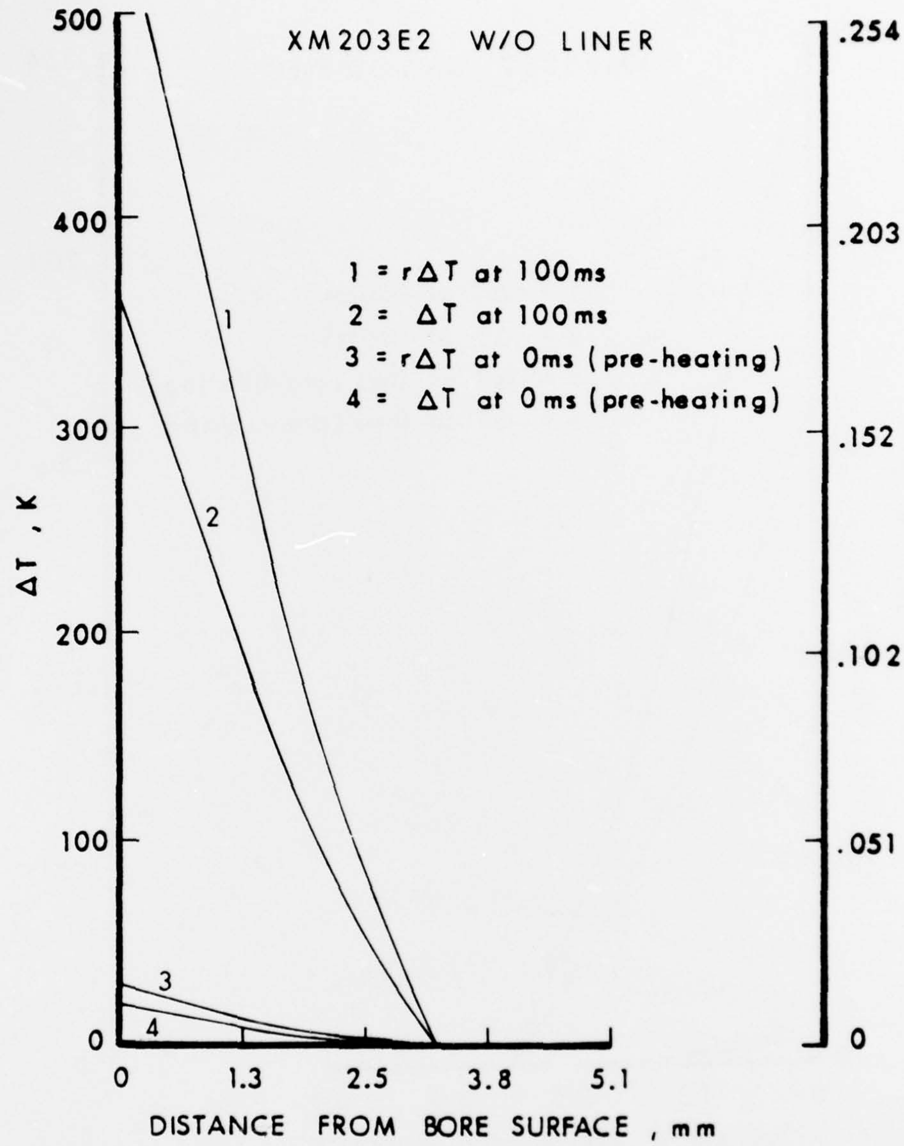


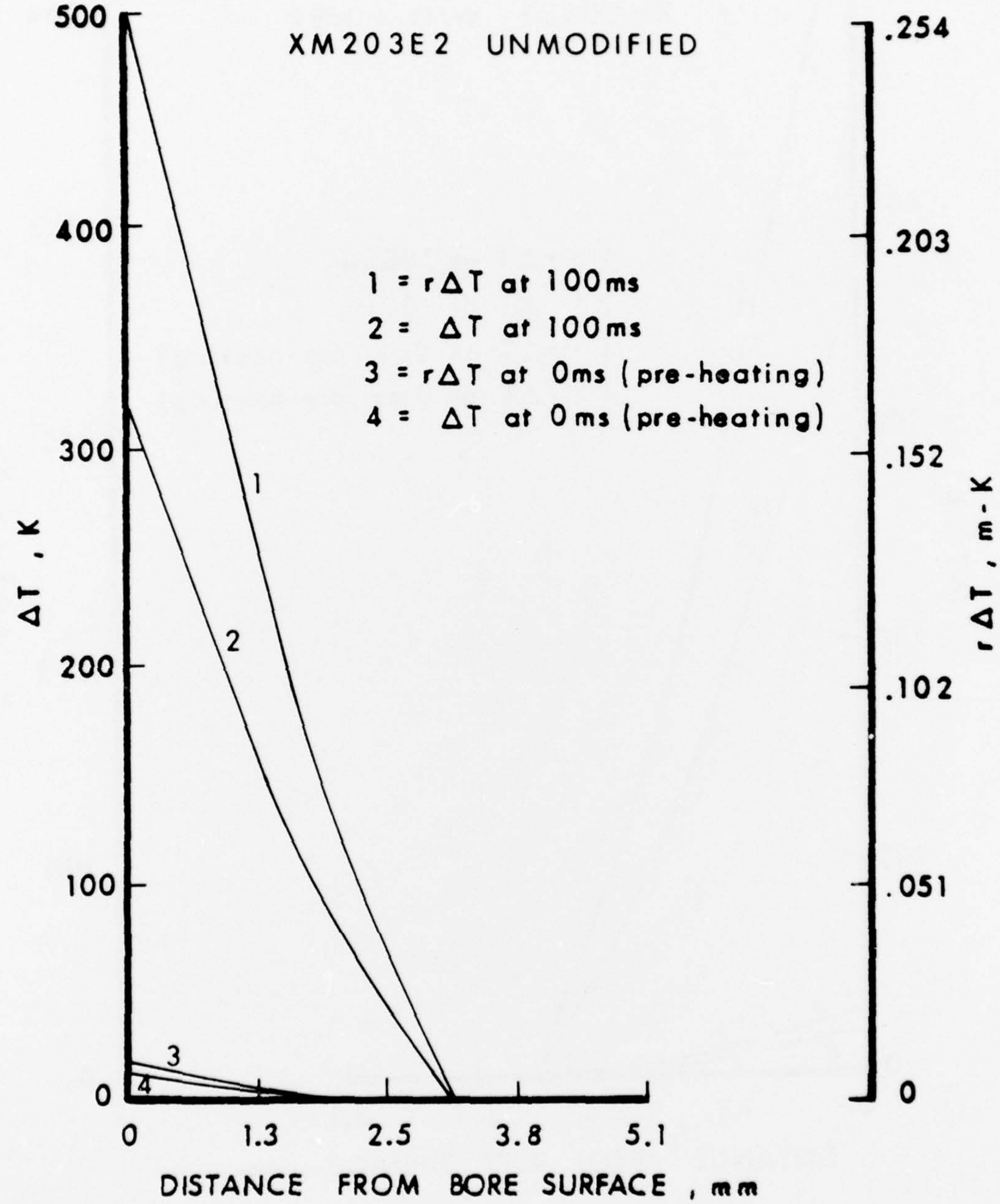
XM201E2 WITH M6 PROPELLANT
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
ΔT , K
r ΔT , m-K
500
400
300
200
100
0
.254
.203
.152
.102
.051
0
1
2
3
4
0
1.3
2.5
3.8
5.1
DISTANCE FROM BORE SURFACE , mm


XM201E1 UNMODIFIED
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
ΔT , K
r ΔT , m-K
500
400
300
200
100
0
.254
.203
.152
.102
.051
0
1.3
2.5
3.8
5.1
1
2
3
4
DISTANCE FROM BORE SURFACE , mm

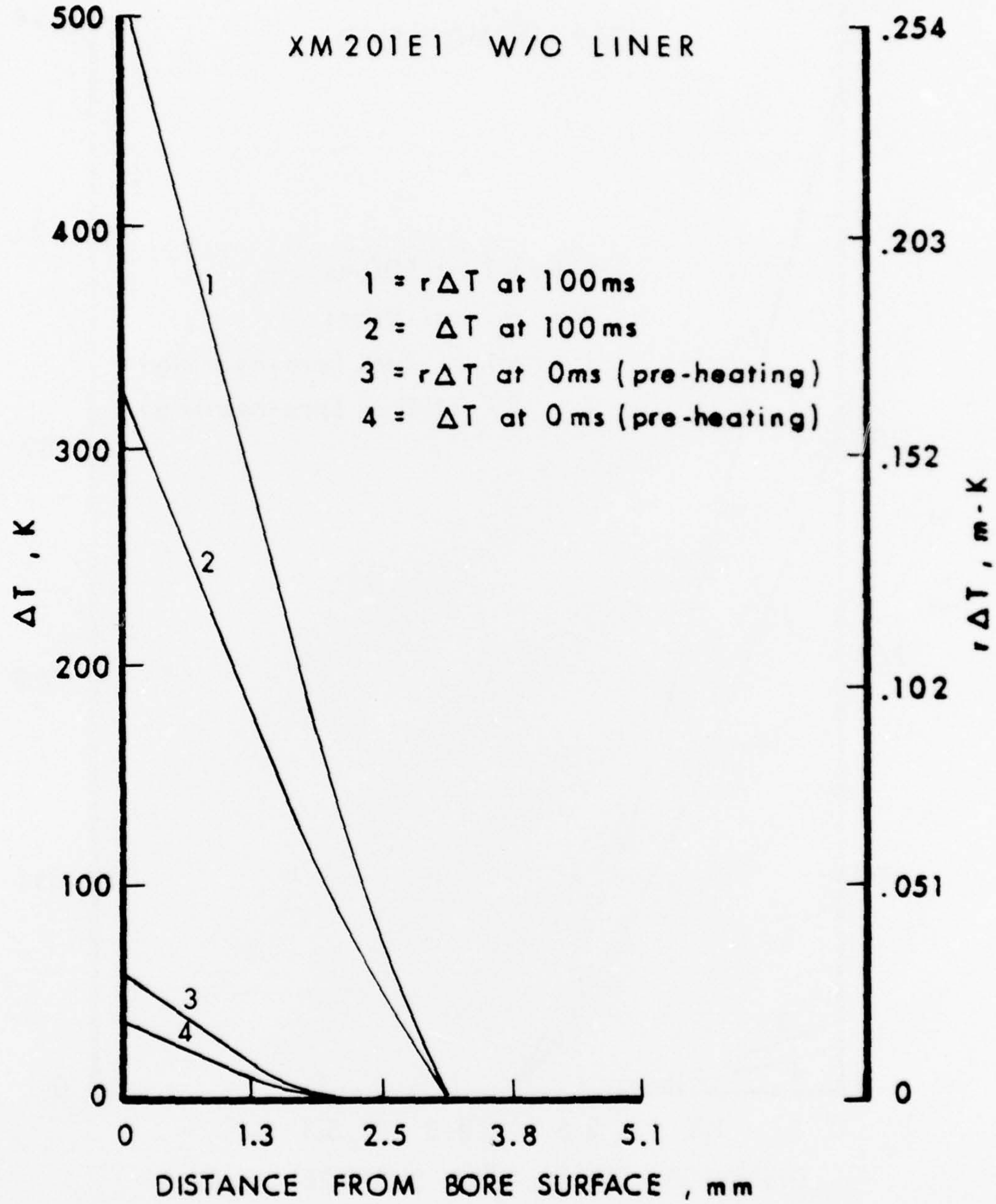

XM119E4 UNMODIFIED
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
500
400
300
200
100
0
ΔT , K
.254
.203
.152
.102
.051
0
rΔT , m-K
1
2
3
4
0
1.3
2.5
3.8
5.1
DISTANCE FROM BORE SURFACE , mm


XM119E4 W/O LINER
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
ΔT , K
rΔT , m - K
500
400
300
200
100
0
.254
.203
.152
.102
.051
0
1
2
3
4
0
1.3
2.5
3.8
5.1
DISTANCE FROM BORE SURFACE , mm

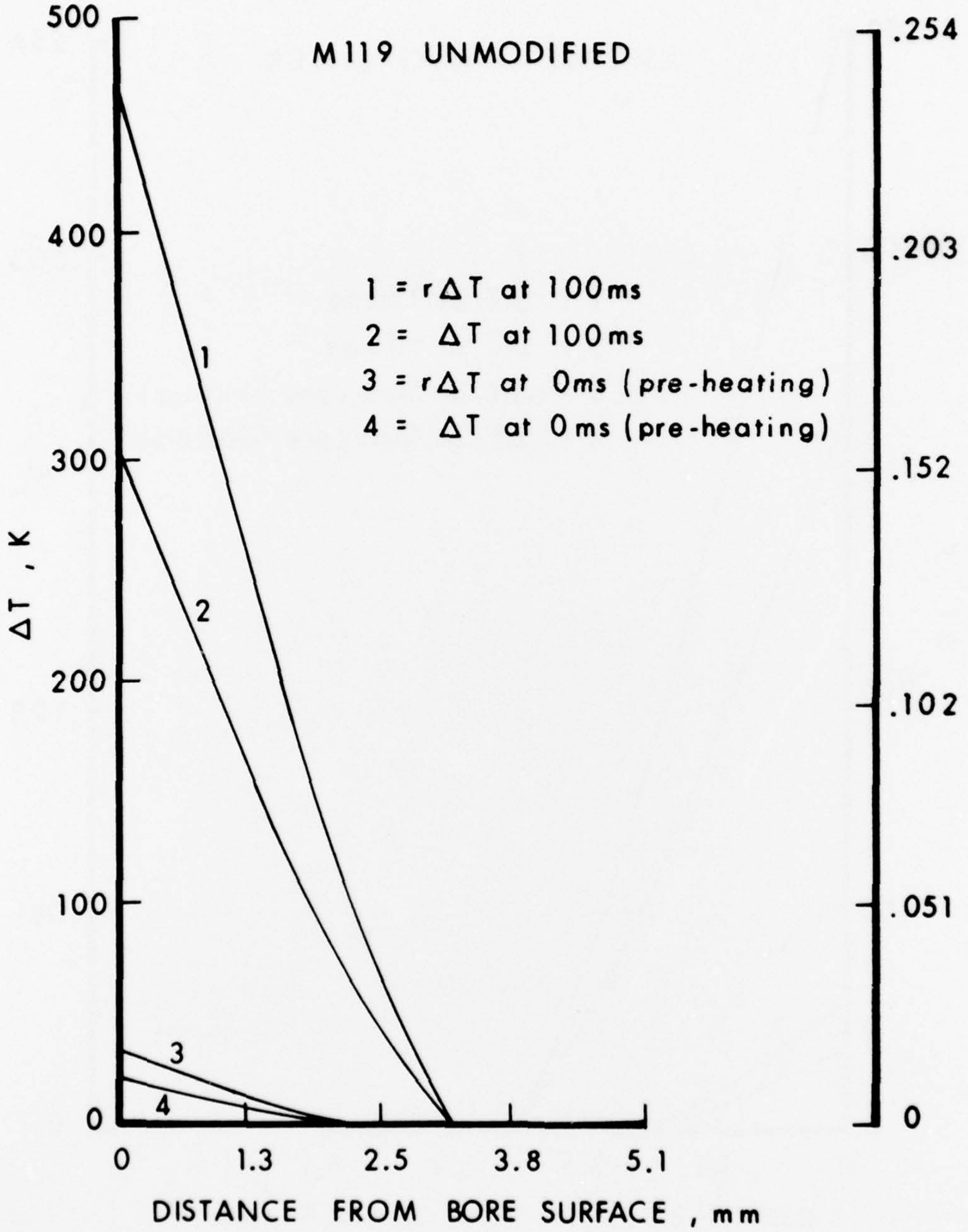

XM203E2 W/O LINER
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0 ms (pre-heating)
ΔT , K
rΔT , m-K
DISTANCE FROM BORE SURFACE , mm
500
400
300
200
100
0
.254
.203
.152
.102
.051
0
0
1.3
2.5
3.8
5.1
1
2
3
4



XM203E2 UNMODIFIED
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
ΔT , K
rΔT , m-K
DISTANCE FROM BORE SURFACE , mm
500
400
300
200
100
0
.254
.203
.152
.102
.051
0
1.3
2.5
3.8
5.1
1
2
3
4



XM 201E1 W/O LINER
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
ΔT , K
rΔT , m-K
DISTANCE FROM BORE SURFACE , mm
500
400
300
200
100
0
.254
.203
.152
.102
.051
0
1.3
2.5
3.8
5.1
1
2
3
4


M119 UNMODIFIED
1 = rΔT at 100ms
2 = ΔT at 100ms
3 = rΔT at 0ms (pre-heating)
4 = ΔT at 0ms (pre-heating)
500
400
300
200
100
0
ΔT , K
.254
.203
.152
.102
.051
0
rΔT , m-K
0
1.3
2.5
3.8
5.1
DISTANCE FROM BORE SURFACE , mm
1
2
3
4

APPENDIX D

APPENDIX D

MULTIPLE STARGAGE MEASUREMENTS [illegible]

Casting Number	Kind of [illegible]	Proof Officer	Model	Number of Rounds	Number	Firing Status (Check One)	Date of Gauging
X	WVT. ARS.	MR. GOETZ 445-5[illegible]	M185	828	22541	After ✓	13 MARCH 7[illegible]

155 M/M How. Tube

155 M/M Tube M185 - [illegible]

Main Bore 39.35" to 238.05"

Distance (Inches From) Rear Face Of Breech	Rear Face of Tube	Gage Meas. Indicated in 1/1000 of an Inch: Land Basic 6.100" Vert	Land Basic 6.100" Hor	Groove Basic 6.200" Vert	Groove Basic 6.200" Hor
242.10	237.40	+.003	+.002	[illegible]	+[illegible]
240.70	236.00	2	.1	4	
239.70	235.00	3	.1	3	2
234.70	230.00	4	.2	3	2
229.70	225.00	3	.1	2	2
224.70	220.00	2	.1	2	3
219.70	215.00	2	.1	2	[illegible]
214.70	210.00	2	2	2	[illegible]
209.70	205.00	3	2	2	[illegible]
204.70	200.00	3	2	2	[illegible]
199.70	195.00	2	2	2	[illegible]
194.70	190.00	1	.2	2	[illegible]
189.70	185.00	1	.2	2	[illegible]
184.70	180.00	2	.2	2	[illegible]
179.70	175.00	2	.2	2	[illegible]
174.70	170.00	2	.2	2	[illegible]
169.70	165.00	2	.2	3	[illegible]
164.70	160.00	2	.2	3	[illegible]
159.70	155.00	2	.3	3	[illegible]
154.70	150.00	2	.2	3	[illegible]
149.70	145.00	2	.2	3	[illegible]
144.70	140.00	2	.2	2	[illegible]
139.70	135.00	2	.2	2	3
134.70	130.00	2	2	2	3
129.70	125.00	2	2	2	3
124.70	120.00	2	2	2	3
119.70	115.00	2	2	2	3
114.70	110.00	2	2	2	3
109.70	105.00	2	2	2	3
104.70	100.00	3	2	2	3
99.70	95.00	3	2	2	3
94.70	90.00	3	1	2	2
89.70	85.00	2	1	2	2
84.70	80.00	1	2	2	3
79.70	75.00	1	3	2	5
74.70	70.00	.000	5	1	6
69.70	65.00	0	5	1	[illegible]
64.70	60.00	+.001	5	1	3
59.70	55.00	5	5	1	1
54.70	50.00	7	5	2	.000
49.70	45.00	15	10	5	0
47.70	43.00	22	14	5	+.001
47.05	42.35	25	16	7	2
46.05	41.35	26	17	16	3
45.05	40.35	28	19	17	8
44.55	39.85	31	24	13	8
44.30	39.60	34	23	15	9
44.15	39.45	+.037	+.031	+.015	+.009
		Vert	Hor		
Pullover Meas.	39.60	6.135"	6.1[illegible]	84%	
				Estimated Remaining Accuracy Life	
				[illegible]	[illegible]

STEAP-MT Form 106A, 1 Aug 75

APPENDIX D

155 M/M Howitzer Tube [illegible] M185								Chamber		
DISTANCE (Inches) FROM					GAUGE MEASUREMENTS INDICATED IN 1/1000 OF AN INCH					
					VERTICAL			HORIZONTAL		
XXXXXXXX XXXXXXXX	XXXXX XXXX	REAR FACE OF TUBE	BASIC DIAMETER	ZERO	GAUGE READING	ACTUAL DIAMETER	DIFFERENCE	GAUGE READING	ACTUAL DIAMETER	DIFFERENCE
		36.10	6.693		+.196	6.696	+.003	+.192	6.692	-.00
		35.50	6.693		195	.695	2	192	692	1
		35.00	6.693		195	.695	2	192	692	1
		34.00	6.693		195	695	2	192	692	1
Triangular		32.00	6.693		194	.694	1	192	692	1
Portion at		30.00	6.693		194	.694	1	192	692	1
6:00 o'clock		28.00	6.693		194	.694	1	192	692	1
		26.00	6.693		193	.693	.000	192	692	1
		24.00	6.693		193	.693	0	192	692	1
Basic	Dia.	22.00	6.693		193	.693	0	192	692	1
(VERT)		20.00	6.693		193	.693	0	192	692	1
MIN	MAX	18.00	6.693		193	.693	0	192	692	1
6.693	6.726	16.00	6.693	6.500"	296	.696	+.003	192	692	1
6.712	6.758	14.00	6.693		230	.730		191	691	2
6.747	6.790	12.00	6.693		264	.764		191	691	2
6.781	6.822	10.00	6.693		298	.798		191	691	2
6.816	6.854	8.00	6.693		331	.831		191	691	2
6.851	6.886	6.00	6.693		364	.864		191	691	2
6.886	6.918	4.00	6.693		399	.999		192	692	1
6.895	6.926	3.50	6.693		413	.913		192	692	1
		3.00	6.693		194	.694	+.001	192	692	1
		2.00	6.693		194	.694	1	192	692	1
		1.50	6.693		+.194	6.694	+.001	+.192	6.692	-.001

SPECIAL MEASUREMENTS

	BASIC	ACTUAL		BASIC	ACTUAL
TOTAL LENGTH OF GUN	-----	-----	ROTATION OF TUBE AT BREECH	-----	-----
TOTAL LENGTH OF TUBE	238.05"	238.05"	MOVEMENT OF TUBE AT BREECH	-----	-----
DEPTH OF BREECH RECESS	-----	-----	NUMBER OF LANDS AND GROOVES	48	48

Borescoped: (Chamber only chrome plated) Light scratches, stains, and other deposits with rust and rust pitting thru-out powder chamber. Chrome lightly chipped from edge of chamber at rear of cut-out portion between 5:00 and 7:00 o'clock. Light erosion and scoring in base metal where chrome is removed. Moderate to light heat checking encircling chamber beginning 10" from rear face of tube (RFT) and continuing forward to 125" from (RFT) in the grooves and to 160" on lands. Moderate to light erosion encircling forcing cone and extending forward to 70" from (RFT). Lands are rounded thru-out eroded area with edges of lands rounded to 105" from (RFT) and driving edges rounded to 120" from (RFT). Light longitudinal scoring encircling bore between forcing cone and 50" from (RFT). Light erosion and scoring on forward edges of bore evacuator holes and port holes. Light scratches, stains, carbon, coppering and other deposits with moderate to heavy rust and rust pitting thru-out main bore.

No photographs or impressions taken at this time.

APG STAMPED (PREV.)	STARGAUGED AND INSPECTED BY [illegible]	REVIEWED BY
RODMAN [illegible]	TIME	COMPILATOR
RECORDER [illegible] ROUGH	PLACE 525	GRAPHED BY

155 M/M How. Tube # 22541 M185
18 MARCH 1976 A.F. 828 Rds.
FOR - MR. GOETZ
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