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THE EFFECTS OF OBTURATORS ON GUN TUBE WEAR

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U.S. ARMY LABORATORY COMMAND

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Modern US projectiles incorporate plastic obturator bands to reduce the ill effects of high temperature gas escaping from behind the projectile. Not all NATO countries use obturators on their projectiles. Currently several of these countries are considering introducing obturators to their projectile inventory. This study was conducted primarily to assess the effects of such a change on previously quantified ammunition interchangeability and gun wear. Of particular interest are potential effects on nuclear projectiles.

Instrumentation employed included embedded gun tube wall thermocouples. These thermocouples were located at selected circumferential and axial locations. The axial locations were selected to measure charge temperature input to the gun tube wall at locations reflecting various countries' current choices of gun tube condemnation measurement points. The circumferential separation of thermocouples allowed continued studies of asymmetric wear effects of stick propellants.

Data comparing US and other NATO propelling charges and projectiles, with and without obturators, are presented and analyzed. Additional data on asymmetric heating effects of stick propelling charges are examined.

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I. INTRODUCTION

Considerable effort has been expended by the US to qualify 155-mm NATO munitions and howitzers in terms of compatibility with US conventional and nuclear munitions. Recently it has become apparent that some NATO countries are considering adopting the use of obturator bands on their projectiles. Concern exists that this modification could significantly alter previously determined parameters, primarily gun tube wear life predictions.

This study was initiated to address this issue by making experimental measurements of heat input imparted to a 155-mm howitzer when firing various combinations of US and NATO munitions with and without obturators. The data were then analyzed in an effort to predict potential consequences to the system from the addition of the obturator. Additional analysis of this data allowed comparisons of the propelling charges employed in terms of total heat input and potential for producing asymmetric tube heating[1].

II. BACKGROUND

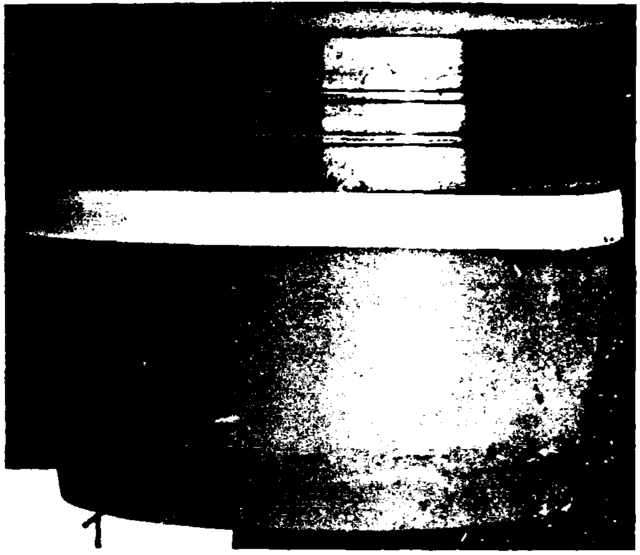


Figure 1. Typical Projectile Rotating Band/Obturator

Obturators serve as a backup to the copper rotating band in retaining propulsive gases behind the projectile. Figure 1 depicts a typical rotating band/obturator configuration. While the copper rotating band is retained on the projectile throughout its flight, the plastic obturator is designed to fragment upon muzzle exit, thereby reducing drag on the projectile. This characteristic has in the past made its use unacceptable to some countries. It was felt that these expelled obturator pieces could present a hazard to personnel near the howitzer. Recently it became apparent that some NATO countries are now considering the use of obturators to extend gun tube life. Since obturators are easily installed on existing projectiles, this change could affect current and future foreign ammunition inventories.

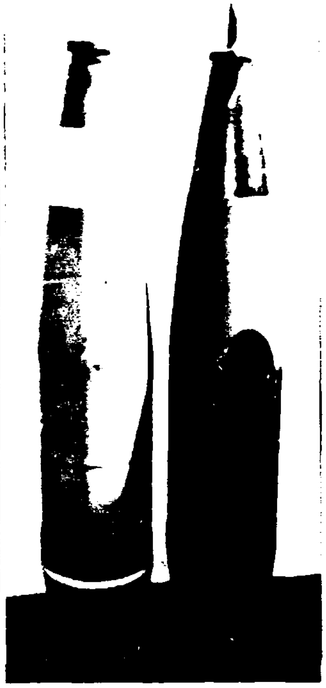
In theory, the contribution of the obturator in sealing of propulsion gases behind the projectile increases as the gun tube wear increases. This results from the ability of the pliable band to flex radially when loaded from behind by propulsive gases. Thus unlike the stiffer copper rotating band which is primarily designed to spin up the projectile in rifled tubes, the obturator can conform more efficiently to irregular and highly worn tubes where rifling lands may be worn or nonexistent. Ideally then, obturator performance would best be measured in a worn tube. For this study, a worn tube which could be modified for thermocouple instrumentation was not available. A relatively new (88 rounds) 155-mm, M199 gun tube instrumented from previous gun wear studies[1,2] was available. It was felt by the authors that if slight changes in heat input could be detected with and without obturators in this new tube, the effects in a highly worn gun tube could be assumed to be greatly magnified.

III. DESCRIPTION OF MATERIAL, INSTRUMENTATION, AND TECHNIQUES

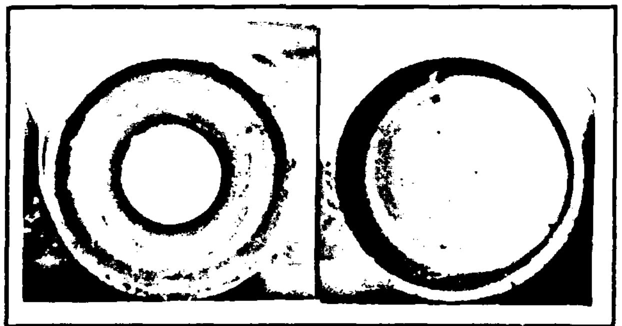
A. Ammunition

The projectiles used in this study were the US M549 and the UK L15A1. These projectiles are compared and contrasted in Figure 2. Note the lack of a rocket assist in the L15A1 projectile. The other difference of particular interest is the lack of an obturator on the L15A1.

Figure 2. M549 (Left) and L15A1 Projectiles



The propelling charges employed in the study were the US and UK top zone charges, the M203A1 and the L10A1 (charge 3) respectively. In addition, the UK L8A1 (charge 2) was also fired. The two UK charges were employed because they were the primary charges used during US testing of the UK FH70 howitzer. The US M203A1 charge was used since it is the rough equivalent of the L10A1. These charges are shown in Figures 3 through 5.



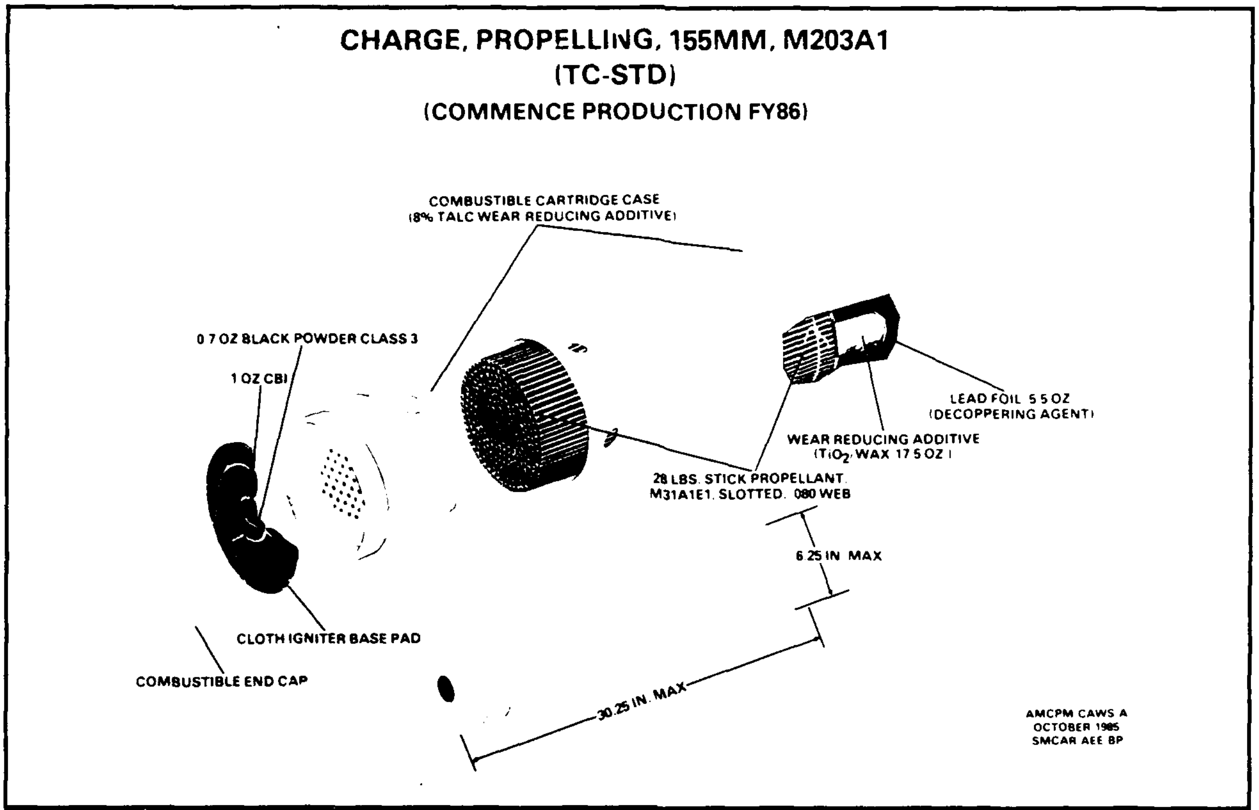


Figure 3. M203A1 Propelling Charge

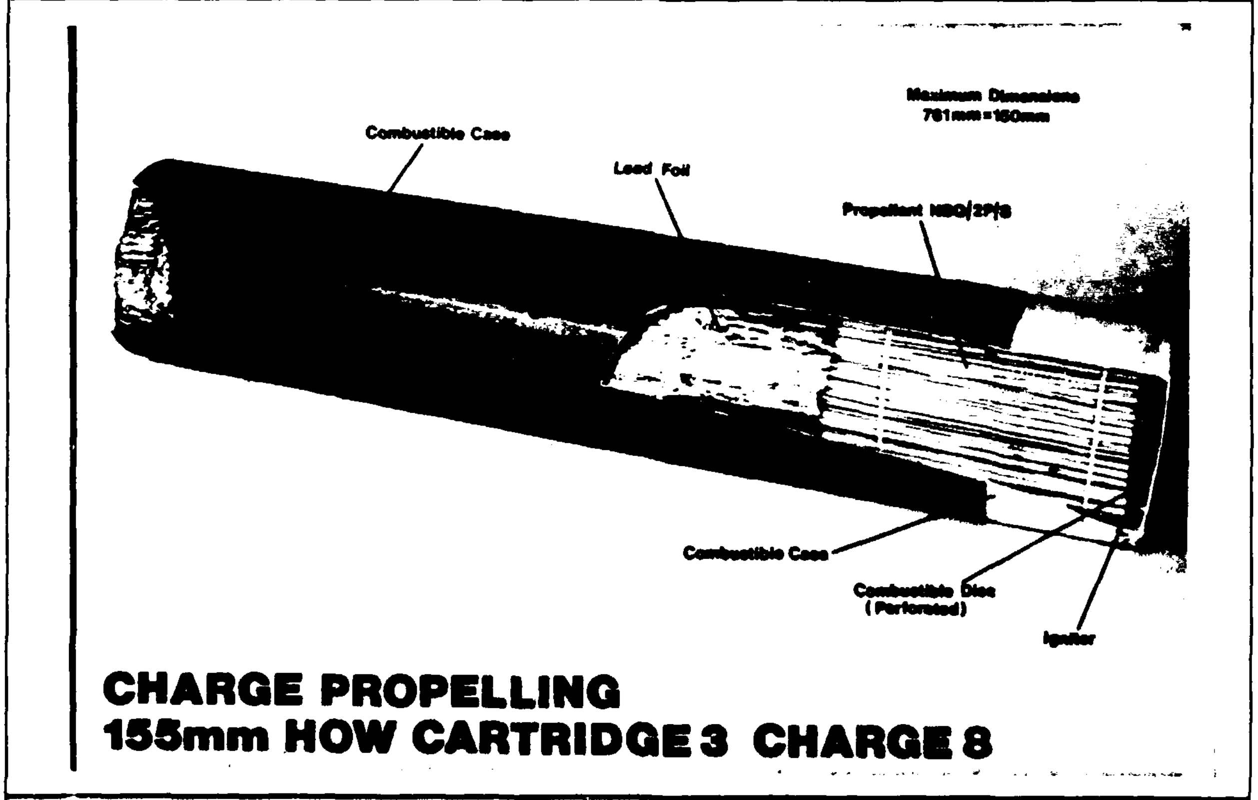
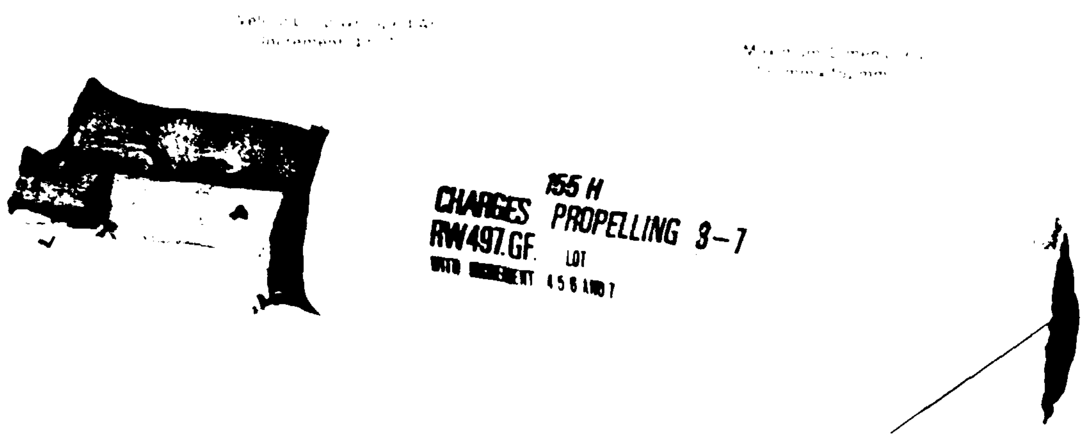


Figure 4. L10A1 Propelling Charge



IGNITER L20 A1
Gunpowder G20 18grammes
propellant NC/200 80grammes

CHARGE PROPELLING
155mm HOW CARTRIDGE 2 CHARGE 3-7

Figure 5. L8A1 Propelling Charge

B. Test Matrix

The basic consideration in the test matrix was to investigate as many variations of obturator/charge/projectile interplay as feasible. To ensure test uniformity all obturators were first removed. New standard obturators were then emplaced on both M549 (normal condition) and L15A1 projectiles (test condition). A separate group of both projectiles was left unbanded. In addition, a third group of M549 projectiles was banded with double width obturators. Limited testing of these double width bands had in the past indicated that these bands had a propensity to extend satisfactory system performance in highly worn tubes beyond that seen with the standard width band.

Table 1 details the test matrix.

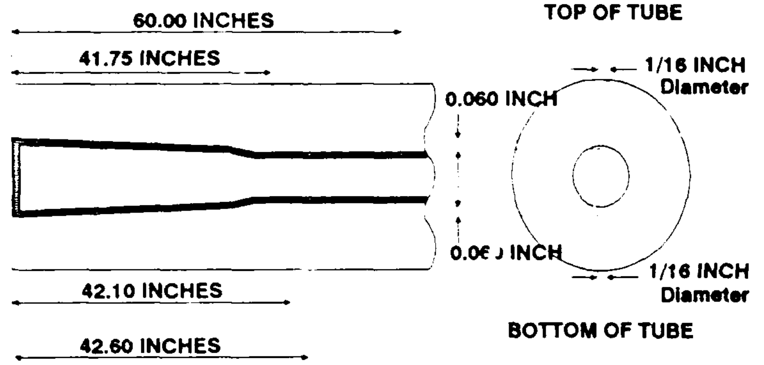
Table 1. Test Matrix

Projectile	Charge	Obturator
M549	M203A1	Standard
M549	M203A1	None
M549	M203A1	Wide
M549	L10A1	Standard
M549	L8A1	Standard
L15A1	M203A1	Standard
L15A1	M203A1	None
L15A1	L10A1	Standard
L15A1	L10A1	None
L15A1	L8A1	Standard
L15A1	L8A1	None

Each group consisted of five rounds (total 55 rounds).
Standard obturator is 549A1 obturator.

C. Experimental Techniques and Instrumentation

The primary instrumentation used to evaluate wear propensities was thermocouples embedded in the gun tube wall. These thermocouples were installed at four axially separated locations near the origin of rifling in a US 155-mm, M199 gun tube. The thermocouple locations are detailed in Figure 6. Except for the furthermost downbore gage, each axially location had at least two circumferentially separated thermocouples, one at the top and one at the bottom of the gun tube. The fourth gage position contained only one thermocouple at the top, while the first axially location had additional thermocouples in both side walls of the gun tube.



Thermocouples at top, sides, & bottom of tube at 41.75 inches from RFT.
Thermocouples at top and bottom only at 42.10 and 42.60 inches from RFT.
Thermocouple at top only at 60.00 inches from RFT.

Figure 6. Thermocouple Locations in Gun Tube

The axial thermocouple locations were chosen for the following reasons. The first set from the breech was located at the point in the origin of rifling currently used by the US to make field measurements (pullovers) of remaining tube life. The third set represented a corresponding field condemnation measurement point used in the UK. The second set was located approximately midway between these sets. This midpoint location has been discussed as a possible unified measurement position. The fourth thermocouple was located where granular propellants have historically produced high secondary wear in the gun tube. Since only stick propellants were used in this study, this position is not one of primary interest. The relationship of these thermocouple positions to a seated projectile (M549) are shown in Figure 7.

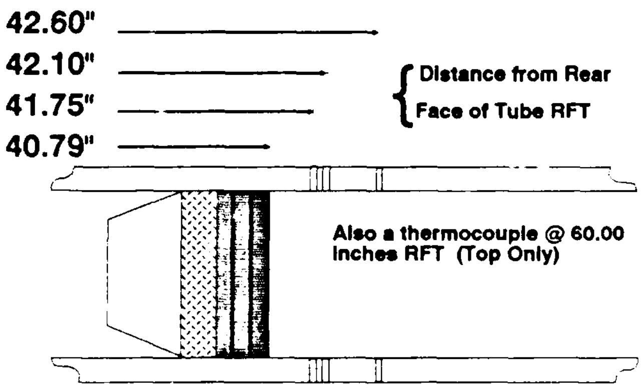


Figure 7. Relative Thermocouple Locations

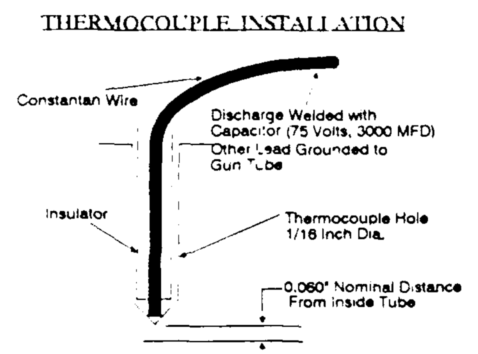


Figure 8. Close-Up of Thermocouple

The actual thermocouple design is shown in Figure 8. The thermocouple junction formed is called a gun tube steel-constantan thermocouple and has been shown to be reliable for near surface (gun tube wall) temperature measurements[3]. A calibration factor of 19.232 degrees C per millivolt output was used for all thermocouples.

In addition to the thermocouples, chamber pressure versus time data were obtained using Kistler 607 gages located at the front and rear of the gun tube chamber. Projectile ramming forces were kept comparable, round to round, through the use of a projectile ramming device which translates an applied torque load to a axial ramming force. This device is shown in Figure 9. Observations of inbore obturator sealing were made through the use of a Multi Angle Downbore Photography Acquisition Device (MAD-PAD). This inhouse designed device allows extreme close-up downbore photography at any gun elevation. This device is shown in Figure 10. In operation, a high speed camera located behind or to the side of the weapon is equipped with a telephoto lens focused on a mirror held by the MAD-PAD. With proper adjustment of the mirror, which can pivot on two axes, the camera "looks" directly downbore. Projectile muzzle velocities were obtained with standard doppler radar techniques.

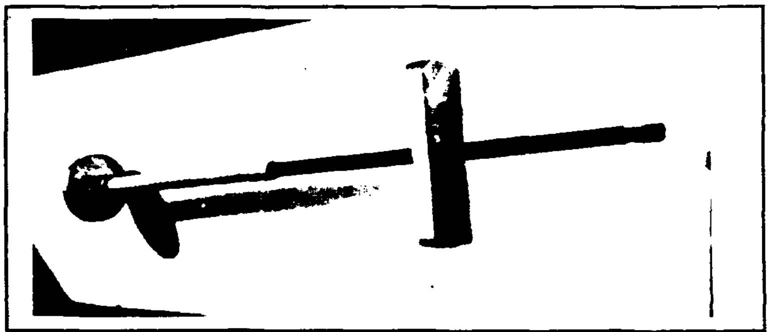


Figure 9. Controlled Load Ramming Device

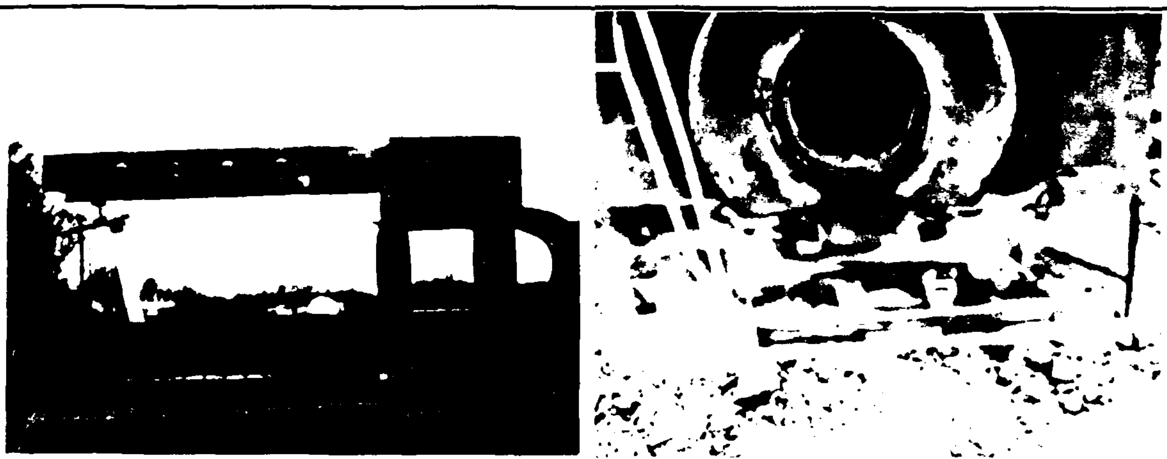


Figure 10. Multi-Angle Downbore Photography Acquistion Device

IV. EXPERIMENTAL RESULTS AND OBSERVATIONS

Pressure-time and velocity data are summarized in Table 2.

Note from Table 2 that with the exception of the last two groups, there was a slight increase in pressure and velocity as the obturator band is added or enlarged. As will be seen, this correlated well with temperature increases measured.

Downbore camera data showed no visually discernible difference in projectile obturation. These data were not surprising since blowby probably would not have been apparent until the gun tube was highly worn.

Table 2. Pressure-Time and Velocity Data

Projectile	Charge	Obturator	Sample Size (Press/Vel)	Pressure/ standard deviation (MPa)	Velocity/ standard deviation (m/s)
M549	M203A1	STD	5/4	353/4.2	821/1.0
M549	M203A1	NONE	5/5	351/3.4	819/2.2
M549	M203A1	WIDE	5/5	357/2.8	822/2.5
M549	L10A1	STD	5/5	338/6.3	827/2.9
M549	L8A1	STD	4/5	330/3.1	683/0.9
L15A1	M203A1	STD	5/5	358/5.1	821/3.4
L15A1	M203A1	NONE	5/5	356/3.7	821/3.4
L15A1	L10A1	STD	5/5	344/2.3	832/1.3
L15A1	L10A1	NONE	4/5	343/2.2	833/1.9
L15A1	L8A1	STD	5/5	334/3.2	682/2.5
L15A1	L8A1	NONE	5/5	335/2.3	684/0.8

Before analyzing temperature data, all pressure time curves were examined to ensure that for the various conditions tested the basic pressure profiles and resultant energy release conditions were basically uniform and comparable round to round. Peak temperatures recorded at each thermocouple location were then used for comparative analysis. Typical temperature profiles are shown in Figure 11.

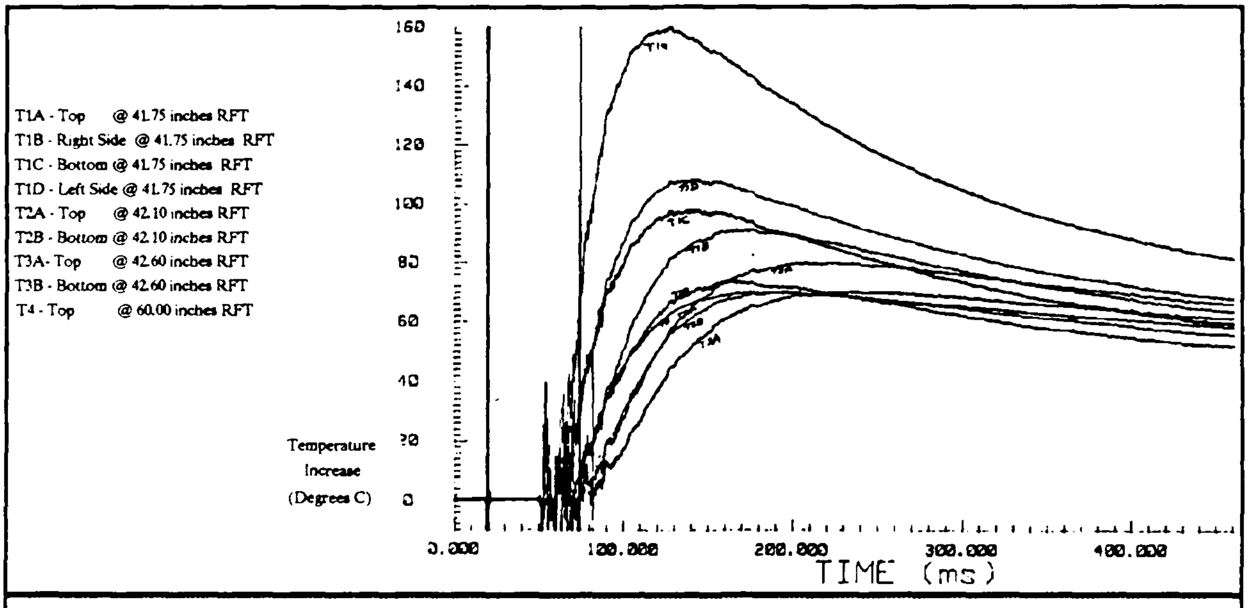


Figure 11. Typical Thermocouple Responses

Table 3. Effect of Obturators at 41.75 Inches from RFT

Obturator Effects

Temperature Rise Degrees C

Projectile/ Charge	With Obturator	Without Obturator	With Wide Obturator
M549/M203A1	138	146	136
M549/L10A1	162		
M549/L8A1	116		
L15A1/M203A1	135	148	
L15A1/L10A1	162	166	
L15A1/L8A1	121	122	

Peak temperatures measured at top of tube , 41.75 inches from RFT.
Standard deviations vary from 2 to 4 degrees.

Temperature data did show slight discernible trends. Table 3 shows the effects of adding or removing obturators as measured at 41.75 inches from RFT. Although some differences are within the standard deviations of the data, all firings show increased peak temperature without obturators. The US charge in particular, shows this effect. As mentioned previously this temperature rise should be much more pronounced in a worn tube as the obturator may not fully compensate for the additional propelling gas sealing required. Note also that under these new tube conditions, the wider obturator appears to have no significant further temperature reduction effect.

Table 4 presents data from the second thermocouple position. Note that while these numbers are lower in magnitude, the same increases in temperature without obturators as seen at the first thermocouple position are apparent with the exception of the lower zone L8A1 charge firings. It is probable that the lower gas volumes produced by this charge produce much more subtle changes in temperature effects which are not detectable in this new gun tube.

Table 4. Effect of Obturator at 42.10 Inches from RFT

Obturator Effects

Temperature Rise Degrees C

Projectile/ Charge	With Obturator	Without Obturator	Wide Obturator
M549/M203A1	74	77	74
M549/L10A1	87		
M549/L8A1	62		
L15A1/203A1	72	81	
L15A1/L10A1	85	87	
L15A1/L8A1	66	63	

Peak temperatures measured at top of tube at 42.10 inches from RFT.
Standard deviations vary from 2 to 4 degrees.

The overall much lower temperatures at the second measurement position were not expected since all thermocouples were within one inch of each other axially. It was theorized that the significantly lower temperature magnitudes at the second (and third) measurement positions were mostly artifacts of different gage distances from the inner land surface. Although great care was taken in the drilling of these gage holes (including through tube wall pilot holes), some variability due to machining, differences in tube wall thickness, and differences in inbore surface removal made exact depth matching impossible. Post test measurements of relative thermocouple depths were taken and are shown in Table 5. Note that these measurements support this assumption. Using the measured relative thermocouple depths the measured peak temperature values at the second and third thermocouple positions could be corrected to simular depth temperature values using standard heat transfer equations. It is not the intention of this paper, however, to compare axial positions to each other, but to use each axial position as a discrete measurement position and examine the changes at each position as a function of the charge/projectile/obturator combination.

Table 5. Relative Thermocouple Depths (Inches)

Thermocouple location From Face of Tube					
41.75 Inches		42.10 Inches		42.60 Inches	
Top	Bottom	Top	Bottom	Top	Bottom
.0625	.0625	.0980	.0824	.0940	.0755

Thermocouple set at 41.75 Inches is the baseline thermocouple. The indicated depth at this position is assumed as a baseline as there is no absolute depth checking mechanism available. The other thermocouple depths are measured relative to this baseline.

Table 6 presents data from the third thermocouple position, where the same general trends described above are seen. All thermocouple positions show greatly increased tube heating when the UK L10A1 charge is fired, which is indicative of its use of higher flame temperature propellant formulations. Note also the expected drop in tube temperature with the lower zone L8A1 charge.

For brevity, only the top thermocouple positions have been used so far for comparative purposes. The data from the bottom and side gages yield basically the same observations. One interesting use for the bottom gages, however, is to again look at the uneven heat distribution produced by stick propelling charges[1,2]. The first thermocouple position is used in an asymmetric heating analysis. This set of thermocouples is best suited for these measurements as it has been calibrated with the gun tube inverted 180 degrees to distinguish thermocouple depth differences at the top and bottom of the gun tube.

Table 6. Effect of Obturators at 42.60 Inches from RFT

Obturator Effects

Projectile /Charge	Temperature Rise Degrees C		
	With Obturator	Without Obturator	With Wide Obturator
M549/M203A1	67	69	66
M549/L10A1	79		
M549/L8A1	56		
L15A1/M203A1	66	71	
L15A1/L10A1	78	79	
L15A1/L8A1	59	58	

Peak temperatures measured at top of tube , 42.60 inches from RFT. Standard deviations vary from 2 to 4 degrees.

Table 7 shows data for the thermocouple temperature difference (top minus bottom thermocouple peak temperatures) for all charge projectile combinations used in this study. Note that while the effect of obturators on this phenomenon is unclear, there in conclusive evidence that the stick asymmetric wear propensity is evident for all the charges tested including the lower zone L8A1.

Table 7. Asymmetric Tube Heating

Projectile/ Charge	Temperature Difference Top minus bottom thermocouplepeak temperature	
	With Obturator	Without Obturator
M549/M203A1	38	39
M549/L10A1	48	
M549/L8A1	24	
L15A1/M203A1	30	45
L15A1/L10A1	43	45
L15A1/L8A1	28	26

Temperatures taken 41.75 inches from RFT.
Standard deviations vary from 2 to 4 degrees.

V. CONCLUSIONS

The following conclusions are drawn:

- *Small decreases in heat input to the gun can be seen when obturators are added to the projectile even in a new gun tube. Thus addition of obturators to some projectile inventories should extend useful gun life.*
- *The ability of the obturator to reduce gun tube wear may be less pronounced in lower zone propelling charges.*
- *Asymmetric wear effects are present in both top and lower zone stick charge firings regardless of changes in other ammunition components such as projectile or obturator.*

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