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TECHNICAL REPORT ARBRL-TR-02265

HEAT TRANSFER MEASUREMENTS IN 105 MM TANK GUN WITH M735 ROUNDS

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September 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE — READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER TECHNICAL REPORT ARBRL-TR-02265	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) HEAT TRANSFER MEASUREMENTS IN 105 mm TANK GUN WITH M735 ROUNDS		5. TYPE OF REPORT & PERIOD COVERED BRL Technical Report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Irvin C. Stobie Timothy L. Brosseau Robert P. Kaste		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Armament Research and Development Command U.S. Army Ballistic Research Laboratory ATTN: DRDAR-BLP Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L162618AH80
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Armament Research and Development Command U.S. Army Ballistic Research Laboratory ATTN: DRDAR-BL Aberdeen Proving Ground, MD 21005		12. REPORT DATE SEPTEMBER 1980 13. NUMBER OF PAGES 24
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Erosion
105 mm tank gun
M735
Wear reducing liners
Heat input

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (clt)

The heat input into an M68 cannon was measured using an imbedded thermocouple technique. M735, M392 and M490 rounds were evaluated with emphasis on the high loading density M735 rounds. Position, type, temperature and gluing techniques of wear reducing liners were evaluated. It was determined that the minimum tube life for the high loading density M735 rounds based on 1.91 mm (75 mil) condemnation criteria would be 220 rounds under the present configuration. This minimum number could be increased to 3820 rounds using techniques described in this report.

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I. INTRODUCTION

Extensive evaluation of the measurement of heat input into a 105 mm M68 tank cannon has been done at BRL.[1,2] The heat input was determined by measuring the change in temperature at four different radial positions in the tube wall at an axial distance of 641.4 mm from the rear face of the tube (RFT). The purpose of this test was to evaluate the total heat input of the M735 round at ambient (294°K) and elevated temperatures (336°K). The study was expanded to show the effect of position, technique of glue application, and type of wear reducing additive on the heat input. M392 and M490 rounds were also fired to correlate this test to previous testing. The heat input values have been applied to an empirical formula derived by Brosseau[3] to infer an erosion rate. The measurements in this test were all made for the "worst case" situation for heat input. All measurement rounds were fired from a clean gun tube. The gun tube was pre-conditioned by firing M467 rounds before the measurement rounds to remove additive residue. It has been found that several additive rounds fired in succession are required to obtain minimum heat input values or "best case" situations.[2] The limited number of M735 rounds available for this test precluded the firing of "best case" series.

II. EXPERIMENTAL PROCEDURES

Heat transfer measurements were made in an M68 cannon with 77 per cent estimated remaining accuracy life.[4] Four constantan wires, 0.13 mm diameter, were welded using a capacitive discharge technique to form constantan-gun steel thermocouples at 641.4 mm (RFT). The thermocouples were located over grooves at a position where vertical land diameter is measured to assess the remaining barrel life.[5] The thermocouple locations are denoted below:

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[1] *T. L. Brosseau and J. R. Ward, "Reduction of Heat Transfer in 105 mm Tank gun by Wear-Reducing Additives", BRL-MR-2698, Nov 1976.* (AD #B015308L)

[2] *T. L. Brosseau and J. R. Ward, "Measurement of the Heat Input into the 105 mm M68 Tank Cannon Firing Rounds Equipped with With Wear-Reducing Additives", BRL-TR-02056, April, 1978.* (AD #A056368)

[3] *T. L. Brosseau, B. B. Grollman and J. R. Ward, "Empirical Formula Correlating Erosion and Heat Transfer", 1979 JANNAF Propulsion Meeting, Anaheim, CA, Vol 1 pp 231-250, March 1979.*

[4] *Based on star gaging data, 19 Oct 1979, tube No. 24849.*

[5] *"Evaluation of Cannon Tubes", Dept of Army Technical Manual, TM-9-1000-202-35, Nov 1969.*

Thermocouple No.	Position	Distance from Bore Surface (mm)
1	3 O'clock	0.73
2	9 O'clock	0.98
3	6 O'clock	1.37
4	12 O'clock	2.50

Table 1 summarizes pertinent characteristics of the ammunition fired in the test series. The gluing of liners in the "as received" liner rounds consists of the application of an approximately 25 mm wide band of glue to the inside perimeter of the liner and applying the liner to the appropriate position inside the cartridge case. The reglued liners consist of application of the glue to the entire inside area of the liner as well as to the effected area of the case. The glue used in both applications was 3M adhesive No. EC 1099. The talc/wax and the TiO_2/wax liners were approximately 375 mm long, 230 mm wide, and 1.5 mm thick for the below the neck applications. A right triangular portion of the liners, reducing the area by 6.4%, was removed for "at the neck" cases to prevent overlap. The average mass of the TiO_2/wax liners was 132 g and the average mass of the talc/wax liner was 141 g. The positions of the liners is shown in Figure 1.

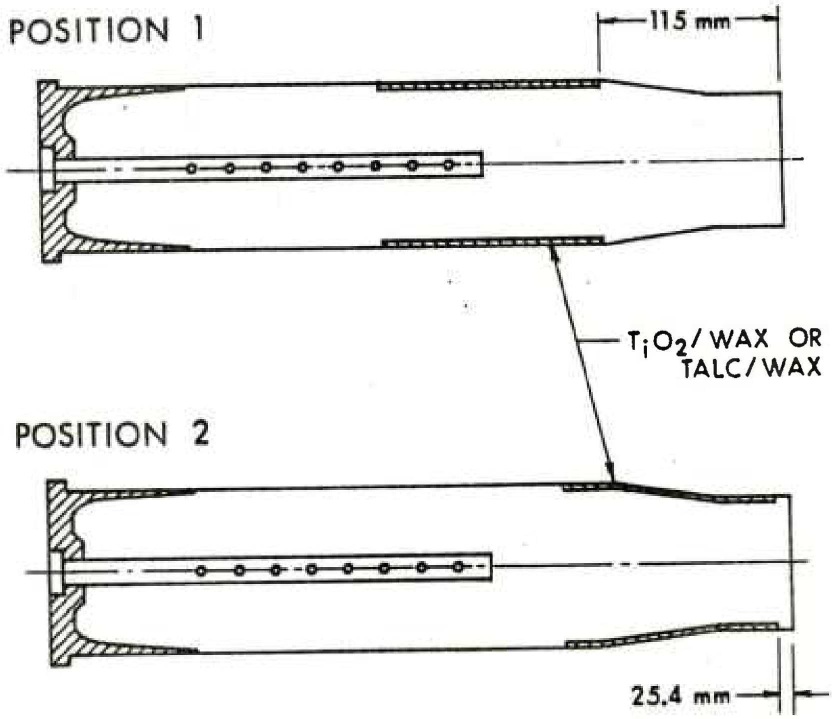

Figure 1. Liners and Positions for M735 Rounds

TABLE 1. PERTINENT AMMUNITION CHARACTERISTICS[6]

Round	Propellant Type	Propellant Web, mm	Propellant Mass, kg	Projectile Type	Projectile Mass, kg	Primer	Muzzle Velocity, m/s	Chamber Pressure, MPa
M392A2 APDS-T (LOT MA-11-3A) (LOT MA-11-7A)	M30	1.16 MP	5.602	M392E3	5.874	M80A1	@63°C 1546[7] @21°C 1486	475[7] 414
M467 TP-T (LOT-MA-30-29)	M1	.086 MP	2.744	M468	11.25	M86	731.9	166
M735 APDSFS-T (LOT MA7TE000E187	M30	1.17 MP	6.046	M735	5.788	M148A1B1	@63°C 1590[7] @21°C 1506	486[7] 403
M490 TP-T	M30	1.35 MP	3.242	M489	10.138	M148A1B1	1174	410

[6] *Artillery Ammunition Master and Reference Chart", TECOM Report No. 1375, Nineteenth Revision, June 1978*

[7] *Private communication with J. O. Pilcher, BRL, September 1979.*

The rounds were conditioned at a constant temperature of either 294°K or 336°K for twenty-four hours prior to firing. The thermocouple responses were amplified using Newport 70 amplifiers and simultaneously recorded on a Honeywell 96 analog tape recorder and a digital ballistic data acquistion system.

III. ANALYSIS AND RESULTS

The firing sequence is reported in Table 2. Using a calibration factor of 52 μV/K, the thermocouple outputs were compared to voltage calibration steps to determine the change in temperature. A typical temperature time plot obtained from the ballistic data acquistion system is shown in Figure 2. Using the method developed by T. L. Brosseau,[8] it was possible to calculate the heat transferred to the gun tube. Three or more round replicates were fired for most modifications with temperature variations similar to those reported earlier.[1,2] The greatest variation range in temperature for any thermocouple was 5K between rounds in a group. This range was seen in the thermocouple nearest the bore surface. The mean temperature of each thermocouple was used in plots of the products of temperature rise and radial distance to the thermocouple vs distance to the bore surface to compute heat input.

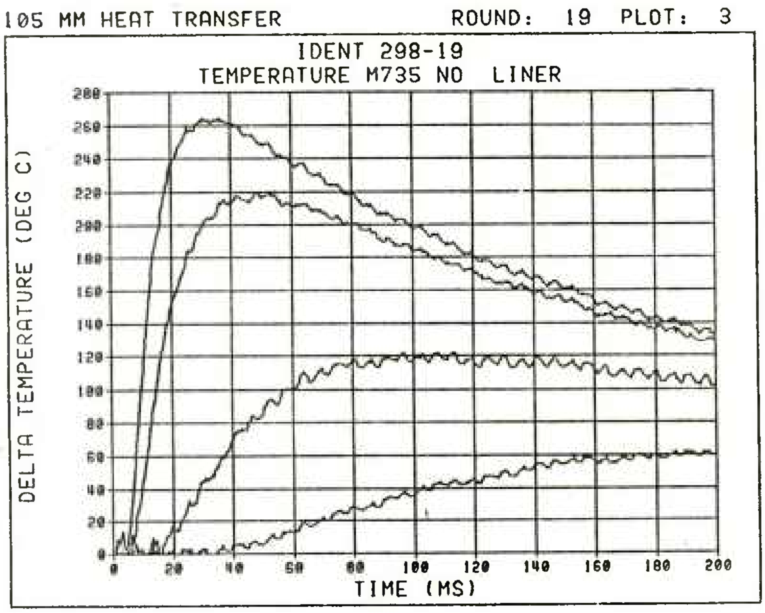

Figure 2. Temperature vs Time for Imbedded Thermocouples

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

TABLE 2. FIRING DATA 105 mm HEAT TRANSFER

Ident	Round	Liner	Position*	Purpose/Remarks
298-1	M392A2	TiO_2	1 as RCD	Check out (Tape Malfunction)
298-2	M467			Clean out (Tape Malfunction)
298-3	M392A2	TiO_2	1 as RCD	Check out
298-4	M467			Clean out
298-5	M735	Talc	2 as RCD	
298-6	M467			Clean out
298-7	M735	Talc	2 as RCD	
298-8	M467			Clean out
298-9	M735	Talc	2 as RCD	
298-10	M467			Clean out
298-11	M392A2	TiO_2	1 as RCD	
298-12	M467			Clean out
298-13	M392A2	TiO_2	1 as RCD	
298-14	M467			Clean out
298-15	M735	TiO_2	1 as RCD	
298-16	M467			Clean out
298-17	M735	TiO_2	1 as RCD	
298-18	M467			Clean out
298-19	M735			No liner
298-20	M735	Talc	2 reglue	
298-21	M467			Clean out
298-22	M735	Talc	2 reglue	
298-23	M735			No liner
298-24	M735	Talc	2 reglue	
298-25	M467			Clean out (Tape Malfunction)
298-26	M467			Check out (Tape Malfunction)
298-27	M467			Check out
298-28	M735	Talc	1 reglue	
298-29	M467			Clean out
298-30	M735	Talc	1 reglue	
298-31	M467			Clean out
298-32	M735	Talc	1 reglue	
298-33	M467			Clean out
298-34	M735	TiO_2	2 reglue	
298-35	M467			Clean out
298-36	Tape Test			
298-37	M735	TiO_2	2 reglue	
298-38	M467			Clean out
298-39	Tape Test			
298-40	M735	Talc	1 reglue	336°K
298-41	M467			Clean out
298-42	Tape Test			
298-43	M735	TiO_2	1 reglue	336°K
298-44	Tape Test			
298-45	M467			Clean out
298-46	M735	TiO_2	1 reglue	336°K

Position 1 and 2 shown in Figure 1.

TABLE 2: FIRING DATA 105 mm HEAT TRANSFER (Cont'd)

Ident	Round	Liner	Position*	Purpose/Remarks
298-47	M467			Clean out
298-48	M735	TiO_2	1 reglue	336°K
298-49	M467			Clean out
298-50	M735	TiO_2	2 reglue	336°K
298-51	M467			Clean out
298-52	M735	TiO_2	2 reglue	336°K
298-53	M467			Clean out
298-54	M735	Talc	1 reglue	336°K
298-55	M467			Clean out
298-56	M392A2	TiO_2	1 as RCD	336°K
298-57	M467			Clean out
298-58	M392A2	TiO_2	1 as RCD	336°K
298-59	M467			Clean out
298-60	M392A2	TiO_2	1 as RCD	336°K
298-61	M467			Clean out
298-62	M735	TiO_2	1 as RCD	336°K
298-63	M467			Clean out
298-64	M735	TiO_2	1 as RCD	336°K
298-65	M467			Clean out
298-66	M735	TiO_2	2 reglue	
298-67	M467			Clean out
298-68	M490	TiO_2	1 reglue	
298-69	M490			No Liner
298-70	M490	TiO_2	1 reglue	
298-71	M490			No Liner
298-72	M490	TiO_2	1 reglue	
298-73	M490			No Liner
298-74	M392A2	TiO_2	2 reglue	
298-75	M467			Clean out
298-76	M392A2	TiO_2	2 reglue	
298-77	M392			No Liner
298-78	M392A2	TiO_2	2 reglue	No Flaps
298-79	M392			No Liner
298-80	M392A2	TiO_2	2 reglue	No Flaps
298-81	M392			No Liner
298-82	M392A2	TiO_2	2 reglue	No Flaps
298-83	M467			Clean out
298-84	M735	TiO_2	2 reglue	
298-85	M467			Clean out
298-86	M735	TiO_2	2 reglue	
298-87	M467			Clean out
298-88	M392A2	TiO_2	1 as RCD	
298-89	M467			Clean out
298-90	M392A2	TiO_2	1 as RCD	
298-91	M467			Clean out
298-92	M392A2	TiO_2	1 as RCD	

**Positions 1 and 2 shown in Figure 1.*

TABLE 2. FIRING DATA 105 mm HEAT TRANSFER (Cont'd)

Ident	Round	Liner	Position*	Purpose/Remarks
298-93	M467			Clean out
298-94	M735	Talc	2 reglue	
298-95	M467			Clean out
298-96	M735	Talc	2 reglue	
300-1	M467			Clean out
300-2	M392A2	TiO_2	2 reglue	No Flaps
300-3	M467			Clean out
300-4	M735	TiO_2	2 reglue	

Several M392A2 rounds were fired to correlate this series of rounds with previous series of 105 mm firings. The effect of temperature conditioned rounds (294K vs 336K) was elucidated as well as the effect of substantially regluing the liners in the case. Table 3 shows the heat input results of the M392A2 rounds with comparison to previous tests, and the reduction caused by regluing the liners.

TABLE 3. HEAT TRANSFER - M392 ROUNDS

Round	Heat Input (J/mm)	Heat Input REF-2 (J/mm)	% Change from Standard Heat Input
M392A2 Standard TiO_2	380	381	-
M392 (No Liner)	451	449	+19
M392A2 Reglue TiO_2	357	-	-6.1
M392A2 Standard TiO_2 336K	388	-	+2.1

There was also a correlation made with reference 2 using M490 rounds without liners. The heat input measured in reference 2 was 471 J/mm and the heat input for this series was 476 J/mm. The glue effects for the M490 round can also be inferred. The M490 with a TiO_2/wax liner had a heat input of 421 J/mm in reference 2, while a similar liner in the same position, but reglued, had a heat input of 404 J/mm fired in this series.

The task of this investigation was to measure the heat input of the high loading density (6.05 kg M30) M735 round and recommend possible means of reduction of the total heat input. The possibilities of heat input reduction evaluated were types of wear reducing additives (TiO_2 and talc), two positions of the liners (Figure 2) and the effect of substantially gluing the liners in place. It should be noted that substantially gluing the liners increases the residue in the cartridge case.

**Positions 1 and 2 shown in Figure 1.*

Figure 3 illustrates the residue effect. Case No. 1 is "as received" M392 revealing no trace of glue or liner material post firing. The No. 2 case in Figure 3 is an M735 that was reglued at the neck. There is glue residue and a small amount of liner residue. The No. 3 case in Figure 3 reveals a great deal more liner residue for the below the neck regluing in the M735 round. It is not surprising that the liner at the neck of the case would result in less residue because of increased combustion turbulence and flow velocity. It is somewhat surprising that the high residue reglued conditions would result in less heat input to the area of maximum erosion, since liner material left in the case does not work as wear reducing additive. This could be explained by the retention of the liner in the case resulting in more effective use of the liner during the entire combustion cycle. Perhaps more additive is applied to the bore instead of blowing the liner down tube.

Table 4 summarizes the results of the M735 tests at 294K. The effects of types of liners, position and glue are revealed as a percent reduction of total heat input from the no liner condition.

TABLE 4. M735 HEAT TRANSFER RESULTS 294K

Liner Type	Position from Figure 1	Heat Input (J/mm)	% Reduction
Without liner	-	477	-
TiO_2/wax*	1	431	10
TiO_2/wax (reglued)	2	375	21
Talc/wax	2	393	18
Talc/wax (reglued)	2	371	22
Talc/wax (reglued)	1	381	20

The M735 rounds were also evaluated at 336K. The no liner condition was not fired due to expected excess wear. The percent reduction of heat input shown in Table 5 is based on the TiO_2/wax liner condition which is the standard M735 with a wear reducing liner. It is interesting to note that the percent reduction of the two cases were not as high as the percent reductions for the same modification of 294K. This can be explained

Standard M735 round with wear reducing additive.

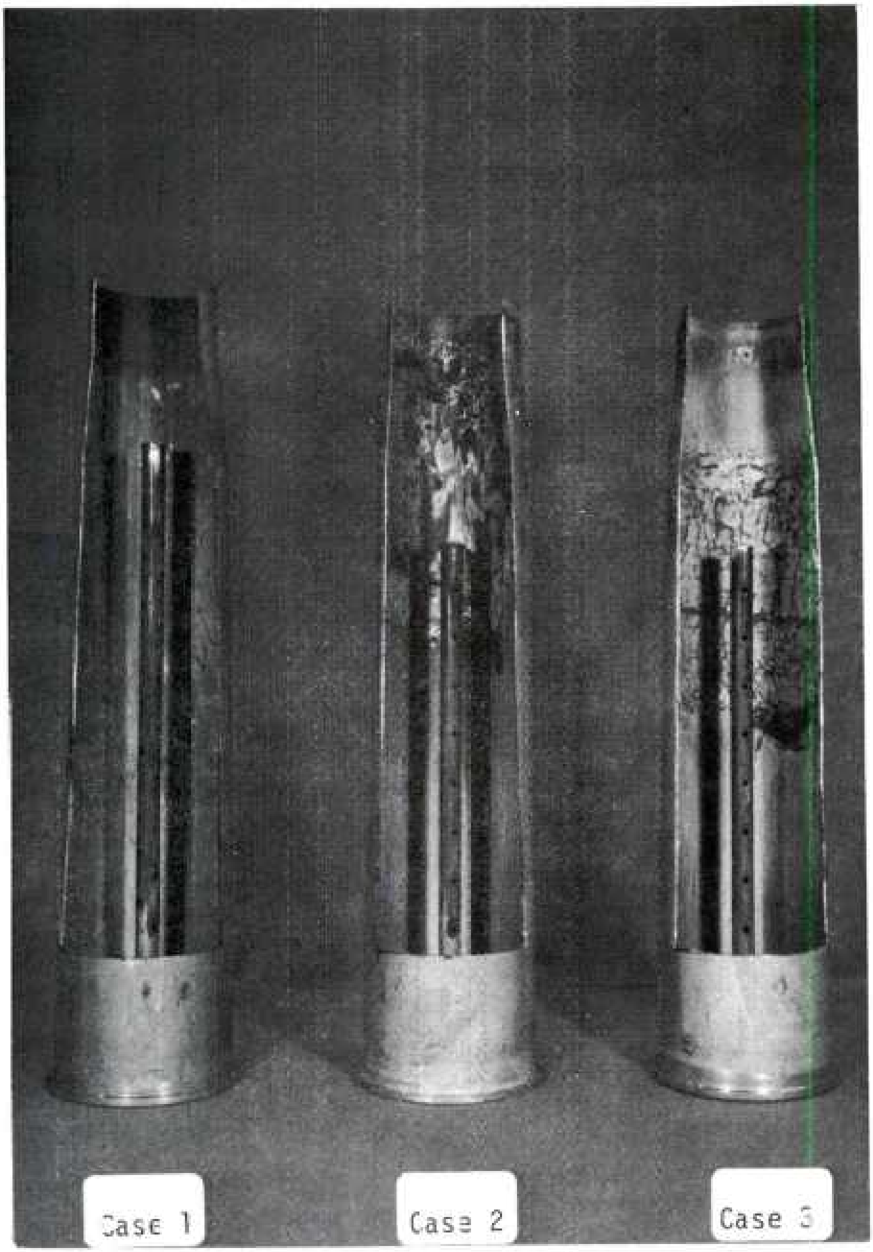

Figure 3. 105 mm Cartridge Cases after Firing

by the reduced effectiveness of the wear reducing liner at elevated temperatures. The reduced effectiveness has been observed in other 105 mm[9] and 155 mm[10] tests.

TABLE 5. HEAT TRANSFER RESULTS 336K

Liner Type	Position from Figure 1	Heat Input (J/mm)	% Reduction
TiO_2/wax*	1	438	-
TiO_2/wax reglued	1	410	6.4
TiO_2/wax reglued	2	398	9.1

T. L. Brosseau derived an empirical formula that correlates heat transfer and muzzle velocity to gun tube wear.[3] This method has proved quite accurate in predicting erosion rates for 105 mm firings that have full scale wear tests. However, as there have not been wear tests for the 105 mm gun with the M735 round, complete confidence in the empirical predictions is not possible. The predicted erosion rates for the M735 rounds at the various initial conditions are given in Table 6. Table 6 also contains an estimate of the wear life of the M68 gun for each M735 type based on a 1.91 mm (75 mil) condemnation wear criteria.[11] The number of rounds used for the wear life in Table 6 does not include the clean out rounds that would be required to fire each of the M735 rounds in a clean gun tube. Although there is some uncertainty with the empirical erosion prediction, the two orders of magnitude difference in wear rate between the no liner and the talc wax cases are significant results.

---

[9] *P. R. Grepps, "Component Development Test of Swedish Barrel-Wear Reducing Additive for 105-mm, M68, Ammunition Components", DPS Report No. 838, March, 1963.*

[10] *D. S. Downs and L. E. Harris, "Relationship of Residue Formation to Wax Used in M203 Propelling Charge Liners", Technical Report No. ARLCD-TR-79042, December, 1979.*

* *Standard M735 round with wear reducing additive.*

[11] *Research Test of Cannon, 105 mm, M68, Mechanism of Erosion, TECOM Test Agency, Report No. APG-MT-5294, September, 1979.*

TABLE 6. PREDICTED EROSION RATES FOR M735 (AT 641.4 mm RFT)

Modification	Heat Input (J/mm)	Wear/rd (μm)	Condemnation Limit (rounds)
Without Liner	477	58.1	30
Talc/wax; Position 2	393	1.5	1300
Talc/wax; Position 2 reglued	371	.5	3820
Talc/wax; Position 1 reglued	381	.8	2390
TiO_2/wax; Position 2 reglued	375	.6	3180
TiO_2/wax; Position 2 reglued; 336 K	398	2.3	830
TiO_2/wax; Position 1 reglued; 336 K	410	4.0	480
TiO_2/wax; Position 1 336 K*	438	14.0	140
TiO_2/wax; Position 1*	431	8.6	220

Table 7 gives the predicted erosion rates for the rounds other than M735 based on heat input and muzzle velocity. These wear rates are compared to actual wear measurements for the rounds where actual star gage wear tests were made.

TABLE 7. PREDICTED VS ACTUAL EROSION RATE (AT 641.4 mm RFT)

Round	Measured Heat Input (J/mm)	Predicted Wear/rd (μm)	Actual Wear/rd (μm)**
M392 (No Liner)	451	20.2	18.0
M392A2 TiO_2	380	0.8	1.07
M392A2 TiO_2; reglued	357	0.2	-
M392A2 TiO_2; 336 K	388	1.4	-
M490 (No Liner)	476	56.3	-
M490; TiO_2; reglued	404	2.5	-

**Standard M735 round with wear reducing additive.*

***Reference 9.*

IV. CONCLUSIONS

1. Heat transfer in the M68 tank cannon is reduced by wear-reducing additives.

2. The reduction in heat transfer is a strong function of the location and gluing technique of the wear reducing liner.

3. Regluing the liner of the M392 round with a substantial amount of glue further reduces the heat input to the gun tube.

4. The present position of the liner in the M735 results in an unnecessarily high and unacceptable heat input. The immediate solution to wear in the M735 round is to move the wear reducing liner to 25.4 mm from the neck of the case.

5. Further reduction in cannon wear can be anticipated by changing the method of gluing the liner in the case. Substantial gluing techniques have a significant effect on heat input to the gun tube. However, there will have to be consideration made for residue in the cartridge case if the gluing technique is changed.

6. The study of the M735 rounds should be expanded to determine the minimum heat input by firing several M735 rounds in succession. The question of secondary wear should also be addressed with liners near the neck of the case. It is believed that reducing erosion at the origin of rifling also reduces secondary wear, but this should be verified with a second series of thermocouples at the area of maximum secondary wear.

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