FOR OFFICIAL USE ONLY

Program Outline of Tests and Design Modifications on the M16 Rifle to Reduce Its Malfunction Rate.

HEADQUARTERS

U. S. ARMY WEAPONS COMMAND

ROCK ISLAND ARSENAL

ROCK ISLAND, ILLINOIS

FOR OFFICIAL USE ONLY

Program outline of tests and design modifications on the M16 Rifle to reduce its malfunction rate.

8 August 1968

By: Leonard R. Ambrosini
Chief Systems Engineer
U. S. Army Weapons Command

Cy 13 of 14

Summary of Program Outline of Tests and Design Modifications on the M16 Rifle to Reduce its Malfunction Rate

1. This program outline of tests of actual hardware and of exploratory design modifications to reduce the malfunction rate of the M16 Rifle has been deducted from a limited amount of samples testing, which have put new lights on the behavior of this weapon.

2. The program, which is not complete and does not include as yet the whole rifle system, foresees systematic testing of a larger population of rifles and ammunition lots, for clearer definition of the intrinsic function of the components, approaching the problem by looking at the technical malfunction sources and not at the several kinds of malfunctions directly. Four specific areas are handled as sources of malfunctions.

a. Buffer

The actual redesigned buffer not only has a major influence on the rifle system dynamics and cyclic rate, but by its masselets bolt anti-rebound function it influences the breech dynamics. It is not joined to the bolt carrier, and does not participate by its momentum to the extraction of the cartridge, as it is desired in case of hard extraction. Its plastic top or bumper is of debatable acceptance. The design of its floating masselets fulfills the scope, but the behavior of these masselets is undetermined during the cyclic operation. The tasks foreseen are:

- Design a joint which will not affect adversely the cyclic operation or the disassembly of the rifle.

- Determine experimentally the functions of the standard and redesigned buffers in regard to the bumper spring and damping characteristics, as well as internal bolt anti-rebound function.

- Design a buffer with control of the masselets position for full mass and momentum utilization at extraction and reliable function of the bumper portion.

b. Gas Tube

The portion of the internal ballistics which insures the internal power of the rifle mechanism is affected by fouling of the gas tube by residues, mostly pyrolysed metallic oxides carried by the propellant gas. To separate the heavy residues from the gas before entrance into the gas tube it is proposed to explore the application of a small cyclone between the port and the gas tube, using centrifugal force. A removable tap will allow cleaning of the cyclone and gas tube.

c. Chamber-Cartridge Clearance at Extraction

This clearance determines the extraction force and can affect the breech dynamics performance. It was found out by using strain gages that the extraction force is high, even with a clean chamber. By subsequent tests it was determined that with no internal chamber pressure, the cartridge is pinched for about a third of the body, where the brass is softer. Using measured internal gas pressure at extraction a radial force was calculated, which through a coefficient of friction correlates with the measured extraction force. It was also found out that the injection of gas into the bolt system launches the bolt carrier backwards, but also pushes the bolt forward, which in turn pushes the cartridge head into the chamber just before extraction, with subsequent deformation of the cartridge-chamber clearance profile. This suggests a major modification by replacing the gas actuation inside the bolt system with a piston located over the bolt, axial with the gas tube. This modification would also eliminate fouling inside the bolt system by gas residues. The tasks foreseen are:

- Determination of chamber-cartridge clearance at extraction, without chamber internal gas pressure, by measurement of diameters of ejected cases and chamber using a population of ammunition lots of different origin.

- Measurement of chamber gas pressure at extraction.

- Subsequent calculation of radial force, with use of chamber pressure.

- Measurement of extraction force by strain gages over extractor with larger population of rounds and no chamber fouling.

- Same measurement with artificial chamber fouling until extraction failure.

- Modification of cartridge case brass hardness profile, possibly with transition at the shoulder, and subsequent verification tests.

- Introduction of a neck taper in the chamber, leaving the cartridge case neck cylindrical.

- Exploratory introduction and test of an actuation floating piston axial with the gas tube, operating inside the receiver, pushing the bolt carrier through a modified key.

d. Propellants

The situation between the extruded IMR8208M and the ball WC 846 is too confused to make an intelligent decision. The ball propellant has a higher specific impetus and its geometry permits a higher loading, with the subsequent advantage of 194 Kg.m per round versus 164 Kg.m for the extruded propellant. Unfortunately, it is only partially burned, approximately 16% exits unburned. It also introduces important fouling in the gas tube, likely created by the deterrent coating if not by unburned propellant. As it is actually produced in batches containing grains of different sizes, it is foreseen to determine the characteristics obtained by the use of a propellant grain of one single size, a specific amount of deterrent and specific curing time. The testing of subsequent sets of grain of different sizes, deterrent amount and curing would determine the influence on pressure-time curve, pressure-displacement curve, bullet velocity, amount of unburned propellant and amount of residue left in the gas tube.

ROLLED BALLS
i.e. DISCS. vs BALLS.

CONTENT

APPENDIX

INTRODUCTION.

The following program has been deducted from a very limited amount of samples, as well as insufficient testing measurements, and basic mechanics laws. It is specifically kept at a minimum level in equations, figures and proposed modifications for general understanding and weapons cost. Sampling of a larger population is needed to confirm and amplify its deductions, as well as the need of a complete testing measurement spectrum, which is partially under way. However, the limited sampling used put new lights on the behavior of the M16 Rifle, and with the accelerated production program actually ordered, it is deemed necessary to proceed at once and fast with design and test of proposed corrections of these findings, at the same time that a more complete test program is achieved to amplify its behavior knowledge. The approach to the problem is performed looking at the malfunction sources and not at the several kinds of malfunctions directly, with a correlation possible to be more accurately established during the progress of the program, which may require additional tasks.

The content which follows has been discussed at Rock Island, Frankford Arsenal, Ballistic Research Labs, and to some extent at Headquarters, U.S. Army Materiel Command.

1. Treatment of the Malfunction Sources.

Four specific areas of the M16 are hereby handled as sources of malfunctions, with no emphasis on their order of importance.

a. Buffer.

Neither the standard nor the redesigned buffer are bound to the bolt carrier, and are not participating with their momentum to the effort to launch by shock the bolt, and extract the cartridge left in charge of the bolt carrier alone. It is felt that joining the two elements can only contribute to the stability of the bolt system operation and cyclic rate, with larger existing mass used. An effort is under way at Rock Island to prove its feasibility, with a simple join idea not hindering the opening of the rifle.

It is also felt that the actual redesigned buffer is of a debatable design, specifically on the use of plastic for spring effect, and it is a general rule that an increase of weight of the bolt system, more easily performed on the buffer, also increases an automatic weapon operation stability. A basic idea on its design is proposed, for which kinematic measurements actually under way at BRL will put more light.

b. Gas Tube.

There is fouling of the gas tube, due mostly to metallic oxides residues carried by the propellant gas and deposited in the tube. These deposits are a small fraction of the total residues, mostly organic, which deposit at lower temperature. These metallic residues, mostly copper, are scraps from the bullet jacket, increased by the design of a gas port not in a barrel groove, but at random and larger than a groove.

It is proposed to use centrifugal forces to separate the metallic residues before entrance in the gas tube, building at the end of obliquity drilled gas port, a small cyclone axial with the gas tube. As the gas flow will first search the larger diameter due to centrifugal force, it is speculated that the heavier residues will deposit at the larger diameter, where a removable and relatively cold tap can be constructed. Opening of the tap will allow cleaning of the tap, cyclon and gas tube.

In addition, this vortex antichamber will introduce a time delay in the operation of the bolt system, useful to permit the extraction of the cartridge at lower chamber pressure. It is to note that a variable antichamber was already under consideration by the Rifles Project Manager's Office, but with no vortex effect.

It is also speculated that the creation of a gas vortex could lead to a closed loop gas system, as a time delay is necessary to reverse the direction of the vortex and have the gas flow back in the barrel. Due to the very small mass of the gas, no gyroscopic effect is expected to stabilize the firing line in the automatic mode, even if the angular velocity is extremely high.

c. <u>Chamber - Cartridge Interface.</u>

It was found out using strain gages on the extractor that the extraction force is high, in the order of hundreds of pounds, increasing with used barrels.

Second, it was considered the fact that in the particular design of this rifle, with gas actuation inside the bolt system, the launching of the bolt carrier and buffer uses the bolt as support instead of the rifle body, and that the bolt can push the cartridge forward in the chamber before extraction. An examination of forces, forward push of the bolt against backward push of the remaining chamber pressure shows a strong imbalance reaching about 300 lbs. for the bolt against 100 lbs. for the cartridge head as data are known sofar. Consequently, it was checked if the forward differential force creates a displacement of the cartridge. The tests were performed with no extractor, with or without gas flow in the bolt system, and comparing the position of the cartridge head for the two alternatives. It was found that the gas actuation rams the cartridge head thereby resulting in a permanent set of 0 to 5 thousandths of an inch. There is no proof that the bolt touches the other side of the locking clearance,meaning it rests on the cartridge head. A computer analysis of malfunctions versus locking clearance showed no correlation.

In the following test set using the same conditions, fired cases were extracted by hand and measured accurately on the outside diameter at room temperature as function of the main axis. Similar measurements were taken on the inside diameter of the used chamber. Correcting for raised temperature of the cases at extraction, approximately 50°C thermal expansion, the clearance was calculated with no chamber pressure. It was found that without gas in the bolt system about one-third of the body taper on the side of the shoulder was slightly pinched, the rest of the body on the head side was free with a clearance of about half-a-thousandths of an inch. The point of clearance to pinching corresponds approximately to the hard or soft brass. However, when the gas was used, and the cartridge pushed in the chamber, the last portion of the body was swallowed and there was practically no clearance all along the body.

As there is a remaining chamber pressure, known actually in the range of 300-400 psi at extraction, it cannot be supported by the elastic strength of the case even partially, creating a larger radial force pushing the case walls against the chamber. This radial force by a friction coefficient gives the friction extraction force, and due to the low taper of 1^{o}, an appreciable loss in dynamic energy. In normal clean firing conditions, the consequence is tolerable, but the friction coefficient is unpredictable in a normal combat use affecting extraction force and cyclic rate and becoming potentially disastrous in case of existance of foreign bodies, as sand, etc. Cleanliness of rifle and magazines is requested, not always possible. Technically, cartridge coating with wax, teflon, etc., can be considered, but it is logical to look for a better clearance at extraction.

Radial force is reduced by reducing chamber pressure, with demand of a time delay before extraction, which is achieved by the introduction of the cyclon mentioned in connection with the gas tube.

Looking further, it is proposed to change the bolt system actuation changing the site of the piston. It can be performed simply by a smaller piston, of same active area, of about 10mm, placed at the intersection of the carrier key and gas tube, and pushing the key and carrier instead to inject gas into the key. The force will not be axial with the bolt, but such is the case in most automatic weapons, and the carrier is long enough to support the tilting moment. The solution is lighter than a long push bar, and it is speculated that it will not require a return spring. With a mass of only about 5 gms, it can float, creating no kinematic interference, and there is space on the receiver to accept it. Latest, but not less important, is the advantage to eliminate propellant contamination inside the bolt system.

d. Propellants

The situation regarding the propellants used in the M-16 Rifle is still too confused to make an intelligent decision. Efforts are continuing at both FA and BRL to clarify the situation.

Two propellants are used. The first is the extruded IMR 8208M, using a single nitrocellulose bare, with a specific impetus of 100 Kg.m/gm. The second is the ball propellant WC 846, using a double base of nitrocellulose and nitroglycerine, with a specific impetus of 106 Kg.m/gm. The geometry of the ball propellant permits a higher loading of 1.83 gm/round versus 1.64 gm/round for the extruded propellant. These two advantages permit the ball propellant to potentially provide 18% more impetus per round versus the extruded propellant. Unfortunately the ball propellant exits with the exhaust gases partially unburned, in an amount measured by samples at BRL of 16%.

The final result in bullet velocity is that the ball propellant meets the specified bullet velocity of 3250 $\pm$ 40 ft/sec, while the extruded propellent is slightly deficient. Hence, the extruded propellant is used only with the lighter tracer bullets.

Second, the ball propellant shows a higher pressure at the gas port, and higher cyclic rate, versus the extruded propellant.

Pages out of order

of the blow back, we will take into consideration only this measured force until refinement of the testing data.

The resulting velocity of the bolt carrier, bolt and cartridge will be given by momentum distribution without rebound by:

$$V_R = \frac{I_{BC} - I_E}{M_{BC} + M_B + M_{cc}}$$

Where I_{BC} = Initial bolt carrier momentum

I_E = Impulse lost by extraction

M_{BC} = Mass of bolt carrier

M_B = Mass of bolt

M_{cc} = Mass of cartridge case

V_R = Basic bolt system recoil velocity

Applying an average impulse loss of 6.5 gm.sec as by RI measurement with new and old barrels, we obtain :

$$V_R = \frac{140.2 - 6.5}{275.3 + 51.4 + 6.2} \cong 4.01 \text{ m/sec}$$

This shock effect is verified by preliminary photographic measurements, with slightly lower results. The dynamic energy of the bolt carrier and bolt can be caluclated as 26,675 gm.cm and the total energy including the initial buffer energy has decreased from 53,825 gm.cm to 45,450 gm.cm, or a loss of 15.6%.

If the buffer was joining to the extraction effort with its total mass, we obtain:

$$V_R = \frac{140.2 + 75.1 - 6.5}{275.3 + 147.5 + 51.4 + 6.2} \cong 4.35 \text{ m/sec}$$

The total dynamic energy will now be 45,680 gm. cm, a practically neglectable increase with an energy loss reduced to 15.2%. Sofar the joining of bolt carrier and buffer has helped only to furnish a potentially larger extraction capability, but practically no energy gain.

from the passage of the bullet under the gas port to extraction is approximately 2.8 millisec, these numbers varying from test to test. The recoil max. velocity of the bolt carrier has been established at FA as 5.0 m/sec respect to ground. The rifle itself recoils, as the exhaust momentum of the bullet (359.1 gm.sec) and gases are higher than the recoil momentum of bolt carrier and buffer, a total of 215.3 gm.sec. Since the velocity of the bolt carrier was established with respect to the ground, neither rifle recoil movement nor the variations due to the propellant will be considered here.

Basically with 5.0 m/sec the bolt carrier has gained a momentum of 140.2 gm.sec and the buffer a momentum of 75.1 gm. sec. Their respective dynamic energies will be 35,050 gm.cm and 18,775 gm.cm, or a total of 53,825 gm.cm.

However, the bolt carrier loses momentum to launch the bolt and cartridge case by shock, and to overcome the extraction force. The effect of the blow back by the remaining gas pressure inside the chamber is small. We know that this pressure is approximately 350 psi, and we must consider only the section of the neck acting as a piston, and not the largest internal section of the case, as the head of the case is partially counter balanced by the active section of the shoulder - with the section of the neck being .039 in ^{2}, the force will be 13.65 lbs or 6,200 gm. The internal pressure is very rapidly decaying, and is below 100 psi after one millisec, when the neck is not yet completely disengaged from the chamber. So we can evaluate the blow back impulse in the range of 3 gm.sec. Considering further that the measurement of the extraction force give us the balance of friction force, acceleration forces and the peak

2. Bolt System Dynamics Considerations

These dynamics considerations of the bolt system movement start from the kinetics aspect, or effects of the existing forces over the masses. A complete effort is actually under study at BRL starting from the kinematics aspect, or displacement of the masses as observed through instrumentation. There is no discrepancy in opinion, the objective being the same.

The M-16 Rifle uses the injection of the propellant gas inside the bolt system. So while the bolt carrier and buffer are launched in recoil, the bolt supports the effort of pushing the cartridge in the chamber. The exact unbalance between the bolt push and the internal pressure applying against the head of the cartridge is not exactly known, it is the task of the planned studies to establish it accurately. But is known that the bolt reaction force is higher, and the head of the cartridge is compressed. Through the cam the bolt during this period is rotated to unlock the chamber, but has no axial displacement. When the cam pin reaches the end of the groove the bolt is suddenly launched by shock pulling with it the cartridge. The bolt carrier is slowed down and the masses of the buffer continue at initial velocity. There is no more energy furnished by the gas actuation, as the cam pin block, any additional stroke between bolt carrier and bolt. Piston effect by the gas tube and key is neglectable, too small working section and past decay of the available pressure. The order of magnitude of the time delays to follow these effects are .3 millisec for the part of the gas flow to travel from the gas port to the bolt system, 2.8 millisec for opening of the bleed holes and an additional .3 millisec for the cam pin to reach the end of the groove and launch the bolt. The total time

Third, the ball propellant introduces more fouling in the gas tube than the extruded propellant. Examination of the residue's surface with ball propellant indicates that besides the metallic portion, the rest has been created by heavy modecules, coming not from the composition of the double base,but most likely from the composition of the deterrent coating. The ball propellant uses 4 to 7% dibutylphtalate as deterrent to compensate for the regressive burning surface in its spherical form.

Ball propellant is produced in batches containing grain sizes from .017 to .027 inches, which are mixed to meet the specification of bullet velocity, peak pressure, unburned propellant percentage, gas port pressure and residues left in the gas tube.

? Evidin

The real effect, however, remains in the bouncing of the damping and floating masselets inside the buffer case. It has been observed that the buffer also slows down to about 4.0 m/sec, which demands a study of the buffer as an element in itself and control of the damping masses position at extraction.

With a recoil velocity of approximately 4.0 m/sec for the whole bolt system, the dynamic energy becomes only 38,630 gm.cm, with an energy loss of 28.1%. It is not so important that energy is approaching the 36,175 gm.cm available in compressing the main recoil spring as by mean specifications. As the specification allows for ± 3,250 gm.cm, there is uncertainty that the plastic top, or bumper of the buffer touches or does not touch the stock of the rifle and we have or we have not full recoil stroke. The case is, if we have a sinusoidal recoil movement broken or not by an apex, it creates a rapid change in the cyclic rate.

To this uncertain situation which exists in horizontal firing, an additional variation of ± 4510 gm.cm must be added if a soldier fires at $\pm 90^{o}$ elevation. This additional variation by gravity on the dynamic energy explains the problems of this rifle firing at negative or positive elevations.

3. STUDIES OUTLINE

In this studies outline, each type of test or analysis is separately listed, in order to achieve better understanding of the effects researched and use of the data by separate working groups. The descriptions are kept at the basic objective level, leaving to each contracted group the task to establish a detailed test procedure. It must be emphasized that such test procedure should in particular eliminate so much as possible systematic errors in the instrumentation and show the ingenuity to separate additional non-researched effects in order to produce a realistic representation of the objective under study.

a. Chamber - Cartridge Clearance at Extraction

The first objective of this study is to establish by accurate measurements statistically the clearance, positive or negative (interference) between a chamber and a cartridge case fired in that chamber, as function of the chamber axis starting from a selected point of reference, using corresponding dimensions of chamber and cartridge case before and after firing. The dimensions of the cartridge should be corrected for thermal expansion, considering the temperature of the cartridge at extraction and the temperature of the cartridge at the time of dimensions measuring. Thermal expansion of the chamber is considered neglectable so far single rounds espaced in time are fired. Consideration of the internal gas pressure at extraction will be performed in a subsequent study. These measurements have to be performed with cartridge extracted without use of extractors and measuring the static extraction force for interference countercheck.

Two sets of tests will be performed, one with no propellant gas injection into the bolt system and no consequent unbalanced force of the bolt pushing the cartridge head in the chamber before extraction. The second with normal gas injection.

The second objective of the study is to establish if there is permanent ramming of the cartridge case in the chamber by the bolt and how the cartridge case is deformed under this bolt pushing effect. It is to note that permanent ramming and cartridge case deformation could exist separately. The position of head of the cartridge will be measured before extraction to establish the existance of the permanent ramming by comparison of the two tests sets.

The method of measurement of the dimensions of the chamber is left at the responsibility of the testing group, either by mold of the chamber, calibrated plugs, etc. The accuracy of measurement must be of .0001", taking two diameters at 90^o apart to compensate for elliptical shape and minimize errors. The measurements must be made at increment of 1/8 inches to avoid erratic clearance behavior for subsequent mathematical treatment.

The test will use six rifles selected from 10 new and 10 used rifles, representing large, medium and small chamber diameters and lengths. Five rounds of ammunition will be used from each current producer, representing five samples sets of rounds loaded with ball propellant and three samples sets of rounds loaded with extruded propellant. Total test population will be 480 rounds, considering gas and no gas injection in the bolt system.

No attempt is made in this study to perform the same measurements with automatic firing, due to the absence of extractors. Also, such attempt is not considered presently necessary, as measurements with strain gages on the extractor show higher extraction forces with single round firing, and also malfunction analyses show an higher malfunction rate with single round firing than with automatic firing.

A third objective of this study will be to determine the effect of the extraction and ejection on the dimensions of the cartridge case, which will be practical to be performed following the same test procedure, with propellant gas injected into the bolt system and use of the extractor. This will represent 240 additional rounds, with dimensions of the cartridge cases compared with the 240 rounds fired with gas injection and extracted manually.

b. Calculation of Radial Force.

From the chamber - cartridge clearance measurements it is possible to establish the total radial force pushing the walls of the cartridge against the chamber, as function of chamber internal pressure, following a method already practiced at Rock Island.

This method traces a function of the pressure necessary to reestablish to zero clearance the clearance or interference obtained by measurement, as function of the axis of the chamber. The body and neck of the cartridge case are considered only, as the shoulder, by its high cone has no effect in the friction extraction force. The difference between this zero clearance pressure curve and the real pressure inside the chamber gives the pressure against the chamber. No deformation of the chamber is considered due to too low pressure. The area or integral gives the total radial force as a function of the internal pressure, which is the objective of the study. Of course, in positions where the strength of the cartridge case supports the internal pressure and some clearance is left, there is no radial force existing.

The data of the cartridge - chamber clearance measurement will be systematically handled, to give a statistical representation of the radial force, with two objectives to be determined, first if there is a high pinching of the cartridge at zero internal pressure, created by the cartridge design, second if there is too high radial force with real internal pressure, created by premature extraction timing.

c. Chamber Pressure at Time of Extraction.

The objective of this study is to determine with sufficient accuracy, 50 psi or better, the value of the propellant gas pressure inside the chamber at the time of extraction. This study is necessary in order to know the value of the total radial force pushing the walls of the cartridge case against the chamber, as well as to determine the importance of the blow back effect on the bolt system dynamics when the cartridge case is cleared inside the chamber.

This measurement is difficult to perform due to thermal transient on the gages, and the need to use gages able to resist the chamber peak pressure and to furnish useful measurements at relatively very low pressures. In particular there is a change of the zero calibration at set-back.

The following guide lines should permit the execution of the study:

First, the influence of thermal transient sensitivity must be eliminated by choice of the type of gage. If not possible, a gage can be mounted at the distance of one inch or so from the chamber, filling the port with hydraulic fluid, which eliminate the immediate thermal transient effect and still offer a sufficient frequency response for this measurement.

Second, due to the smooth shape of the tail of the pressure-time curve, gages with lower frequency response than the standard 100 KHerz can be used, which allows selection of higher sensitivity models.

Third, to avoid the loss of initial zero calibration, the reading of the pressure at extraction can be performed using the asymptotic tail of the curve as new zero calibration.

Fourth, theoretically, when the bullet is sufficiently out from the muzzle so not to interfere with the exhaust gases, the pressure decrease in the chamber is asymptotic with time. This allows to plot the pressure-time curve on a semi-log paper, where it should show a straight line if the zero calibration is correct, as well as furnish a coefficient of decay with time. Measurements obtained with insufficient accuracy in zero calibration can be corrected using this technique.

The measurement of the pressure must be performed in the chamber itself, and not at the mouth of the cartridge, to avoid correction factors. This obliges the tester to use a test barrel and not a rifle. It will be useful but not absolutely necessary to obtain the corresponding high pressure pressure-time curve in the same time. However, accurate time reference is necessary, the exit of the bullet signal is sufficient.

Tests have to be performed with a population of rounds, firing five rounds per lot of ammunition by each producer, as by chamber - cartridge interface test, or a total of 40 rounds.

d. Extraction Force by Strain Gages.

A satisfactory initial method has been used at Rock Island to measure the extraction force using a strain gage mounted on one extractor and obtaining this force as function of time, as well as the integral of force by time, or linear momentum lost by the bolt system for extraction of the cartridge.

The same method should be used to obtain both extraction force and extraction momentum loss on the six rifles used in the chamber - cartridge clearance measurement study, to establish a correlation between the two methods. This means 240 rounds, firing 5 rounds of each ammunition lot per rifle, five sets of ammunition loaded with ball propellent and three sets loaded with extruded propellant. No effort should be done to accomplish this test in conjunction with a preceding test, as the only additional expense is the cost of the rounds, and no interference between tests is desired.

In order to insure the best results, an examination should be made of the actual existing instrumentation, in particular concerning frequency response, strain gage, etc. The natural frequency of oscillation of the extractor should also be checked.

e. Extraction Force With Contaminated Chamber

A description of this study has not been discussed so far, but it consists in using one rifle and a fixed lot of ammunition, and to determine the variation of the extraction force with several types of contaminants in the chamber. Standard type of contaminants can be selected from standard TECOM testing procedure.

f. Buffers Characteristics

The buffer of this weapon full fills two separate functions, which, conventionally, are performed by two different elements. The first function is the high rate spring at the end of the recoil stroke, to which eventually a damping effect can be added, which is the case in this weapon. Such damping effect stabilizes the cyclic rate by absorbing excessive dynamic energy at recoil, but also affects the cyclic rate at high positive or negative firing elevations, as recoil velocity and return in battery velocity does not compensate.

The second function is to stop the rebound of the bolt at return in battery by shock of an additional mass. Conventionally this additional mass is kept at some distance from the shock interface by a spring and needs damping to avoid that and by rebounding itself, it unlocks the bolt by secondary effect. It is a matter of dynamic energy destruction, necessary to avoid miss firing or firing with unlocked bolt.

Two designs of the buffer have been used with the M-16 Rifle, the first weighing 57 gms and the second, actually in use, weighing 147.5 gms. The new heavier model reduces the cyclic rate, and is used in combination with ball propellant, which furnishes a higher gas port pressure. The advantage of this combination is however, still debated.

The first model was mainly performing the function of spring effect at the end of the recoil stroke, using a set of half-conical spring rings, with a cone of $\pm 15^{\circ}$. It was affected by sticking, which could have been corrected by a larger angle and different material. Its bolt rebound stop effect was neglectable, the damping mass represented by its aluminum end being too small.

The new model was designed having in consideration the stop of the bolt rebound, and uses a chain of cylindrical masses separated by discs of butylrubber. The principle has to be considered sound for the desired effect, the butylrubber performing both the spring and damping effects. However, for full effect it uses a gap in the packing of the masses, to compensate for slow down of the bolt system in locking the chamber. As a result of the free floating construction, these massed do not contribute later to the extraction of the cartridge case. The spring function at the end of the stroke is performed by a plastic polymethane top, having both spring and damping characteristics, which are function of temperature. Also, plastic flow, need of time of relaxation of the material and warming up during automatic firing enter into consideration.

Since the functions for both buffers can be experimentally measured and also calculated, the objective of this study is to establish realistic functional characteristics of these two buffers. The buffers will be examined as individual elements, separately from the dynamic behavior of the bolt system, under variation of temperature and wearing. The characteristics of the rifle will be used only to establish the spectrum of use of the buffers.

g. Ball Propellant Individual Parameters Effects

rolled & unrolled

The objective of these tests is to establish which rifle system characteristics are obtained by the use of a ball propellant grain of one single size, a specific amount of deterrent coating, and a specific time of curing at elevated temperature for deterrent migration in the grain, instead of using blended batches. The results of these tests are not intended to be repeated in production, but to show individual effects in order to make intelligent decisions.

First, the various populations of grain sizes, coming from a single double base batch, will be screened for size, by sieving, and divided in sets of grains of progressive diameter steps.

Second, each set will be divided in secondary sets, which will be coated by a progressive amount of deterrent. Zero deterrent should be considered, even if inferior ballistic efficiency will negate later its use or its testing.

Third, each secondary set will also be divided in subsequent sets, to which progressive steps of curing will be applied.

The tertiary sets will be submitted to a sufficient amount of firing to determine the pressure-time curve, the pressure -displacement curve, the bullet velocity, the amount of unburn propellant and the amount of residue left in the gas tube. It is suggested that the pressure - displacement curve should be produced electrically at the same time with the pressure-time curve, and with sufficient accuracy to show the gas port pressure.

The procedures of this study can be detailed further by FA, which have the mission of small caliber propellant.

4. Design Modifications Outline

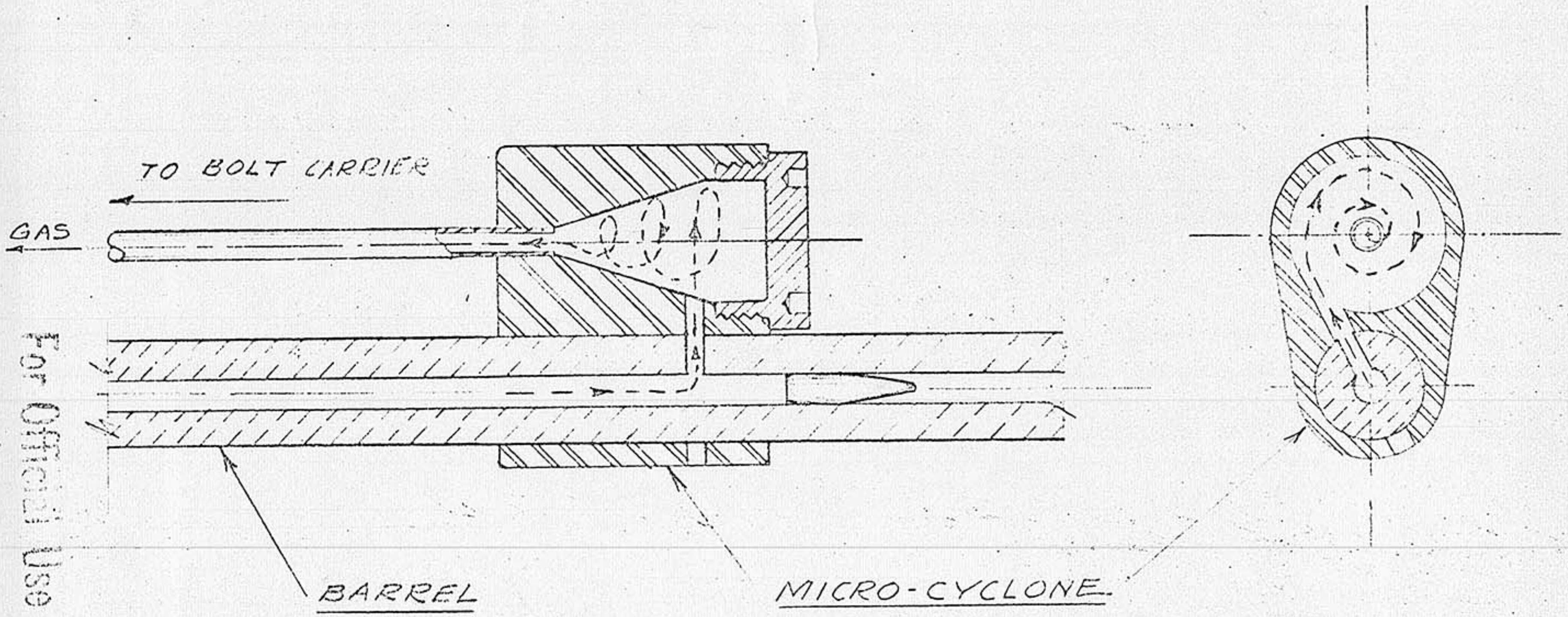
a. Cyclone Between Gas Port and Gas Tube

The two objectives of the incorporation of a cyclone chamber between gas port and gas tube are, reduction of the heaviest residues fouling the gas tube by centrifugal force and delay of the gas transmission to the bolt recoil system to extract the cartridge at lower chamber internal pressure.

The procedure will consist in designing, intuitively, an experimental device in the sight bracket which contains a conical chamber for inducing gas swirl by a obliquely drilled gas port. It is to note that such device can be designed more on the side of the chamber, using larger gas pressure and smaller gas port. As the gas will first search the largest diameter and the heavy residues will be maintained at the largest diameter by centrifugal force, this means that the top of the conical chamber should be removable, in order to clean it. It also will be provided that through such opening the gas tube can be cleaned, which is the reason to design the conical chamber in the sight bracket. The device will provide experimental verification of the theory by showing that heavy metal particles are removed from the gas flowing into the gas tube and stored on the top and that the bolt pressure-time curve record shows a delay. A sketch of such cyclone is attached.

It must be expected that several devices with different shape and size can, as necessary, be built and tested in order to obtain a parametric view of its effect. In parallel with the intuitive models a mathematical calculation of gas flow theory for this cyclone will be performed, and results correlated. However, the experiment phase of this project should not be delayed by the mathematical formulation.

SKETCH NO 140213
AMSWE-RET



M-16 RIFLE
CYCLONE BETWEEN GAS PORT AND GASTUBE
U.S. ARMY WEAPONS COMMAND
ROCK ISLAND, ILL.

DESIGNED BY L. AMBROSINI
DRAWN BY F.R. GRUNER
5-7-65 SCALE FULL SIZE

The size of the gas port required by the additional effect of the cyclone is not known. There is a gyroscopic effect precluding the vortex change of direction without a time delay, practically transforming the system from open loop to closed loop. On the other side more gas is needed to fill the additional chamber. The feasibility study will determine if the actual gas port is adequate, and consider if two gas ports or an advanced position of the cyclone using higher pressure are needed.

The composition of the residues will also be examined. FA test have shown that the residues in the tube, largely metals, are in the magnitude of .015 milligrams/round. BRL test have shown that the total residues, mostly inorganic, collected at total gas expansion with no back pressure after the gas tubes, are 3 milligrams/round. As the centrifugal force is on the order of 10,000,000 g, the study will determine whether too much residue is collected and provide adequate data for design modification to decrease the swirl.

From the experimental devices and gas flow theory, information will be obtained to design a prototype model. This model will be subjected to enough firing to verify that it provides a degree of improvement over the existing system both in reduced dynamic extractor force and reduced residue deposits in the gas tube. Feasibility study will be considered complete when the two objectives are obtained.

If the objectives are obtained, the final configuration taking in account the interface with the rest of the rifle system will be part of a follow-on project.

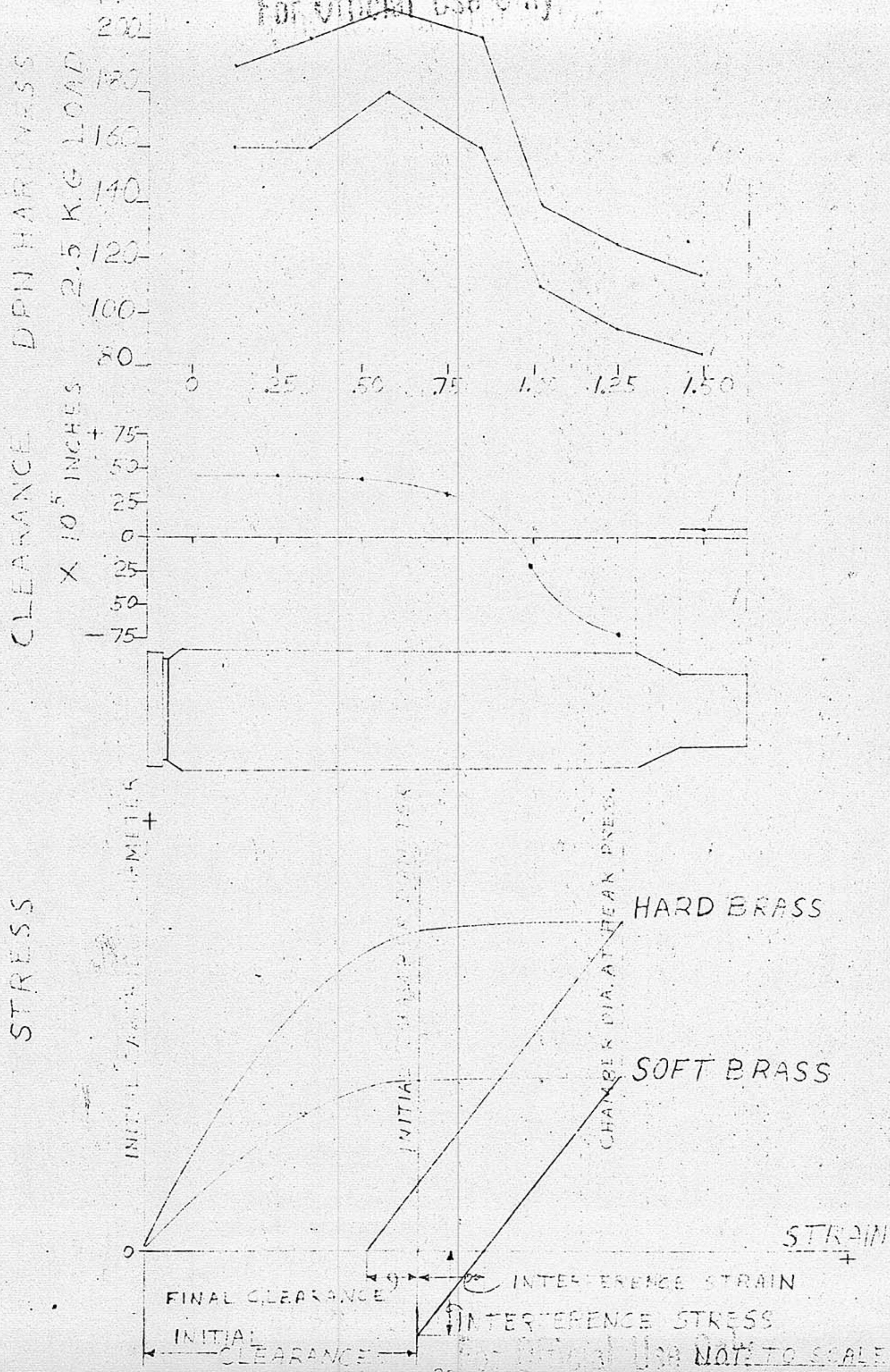
b. Cartridge Case Brass Hardness Profile

From the test samples taken at FA and reduced at RI, it appears that without gas injection in the bolt system and no internal pressure in the chamber, one third of the cartridge case is pinched on the side of the shoulder. The clearance and interference profile closely follow the hardness of the brass, as shown in the adjunct picture.

Following a classic stress-strain diagram, after the cartridge has followed the chamber expansion through plastic deformation, in the hard brass zone there is sufficient stress return capability to create a clearance at the time of extraction. This is not the case for the soft portion, which remains pinched even without chamber internal pressure. The chamber inner and outer diameter being practically cylindrical, there is no default of sufficient rigidity by the chamber.

The objective of this cartridge case hardness profile change is to extend the high hardness to the complete body of the case, so far as practical in production. The neck must remain soft, for storage condition, as hard brass under the stress to hold the bullet will crack in storage. There is no importance on the hardness of the shoulder from the point of view of crushing the shoulder at chambering. The energy to crush the shoulder during the actual maximum chambering stroke of .002" is in the magnitude of 150 gm cm, against 36,175 gm cm stored in the main recoil spring, which makes the ramming energy of the bolt return in battery overwhelming by two orders of magnitude.

Consequently, the shoulder appears to be the best place for the hardness transition zone, dependent only upon production methods. It is possible that the current method which has the main portion of the body in water for cooling and to


DPH HARDNESS 2.5 KG LOAD
200
180
160
140
120
100
80
0
.25
.50
.75
1.00
1.25
1.50
CLEARANCE X 10^5 INCHES
+75
50
25
0
25
50
-75
STRESS
INITIAL CHAMBER DIA.
INITIAL CHAMBER DIA.
CHAMBER DIA. AT PEAK PRES.
HARD BRASS
SOFT BRASS
0
STRAIN
+
INTERFERENCE STRAIN
FINAL CLEARANCE
INTERFERENCE STRESS
INITIAL CLEARANCE
NOT TO SCALE

heat the neck by gas flame, should be changed to a more modern and accurate induction heating method.

A sufficient number of rounds will be experimentally manufactured following the objective of this project and will be tested in one rifle without gas injection in the bolt system to prevent influence of the bolt ramming action before extraction or in a test barrel. The diameters of the extracted cases will be measured following the same procedure as used in preceding studies to measure chamber - cartridge clearance. The modified hardness profile rounds will be compared to a set of rounds of standard brass hardness profile as now in production.

If necessary, additional sets of rounds will be produced experimentally with various hardness transition zones, tested and compared following the same procedure.

The experimental rounds will be examined to check defects which will interfere with the objective of the project.

When the feasibility of the project is proven a proposal will be prepared to indicate what adequate means will be necessary to apply in the production line to obtain cartridge case with the new brass hardness profile.

c. Neck Taper Angle

Actually there is no taper at the neck of the cartridge, either on the cartridge or the rifle. By the samples examined in general, there is no pinching of the neck, but occasionally there is a pinching, which by non-existence of a taper means a small loss of energy at extraction.

For Official Use Only

Another side of the design is that the bullet is better held by a cylindrical neck. However, the soft brass of the neck at high pressure will assume the contour of the chamber by plastic deformation. Therefore, if the neck portion of the chamber has some taper, the cartridge neck will be chambered cylindrically, but will be extracted conically.

The objective of this study is to machine on the neck portion of the chamber a taper at increasing angle by step of one degree, to fire a sufficient amount of rounds and check the progressive defects which will appear between neck and shoulder. From these tests an optimal angle of the chamber neck taper will be established, which will reduce this small but unneeded loss of energy at extraction, without compromising the structural integrity of the cartridge case.

d. Join Between Bolt Carrier and Buffer

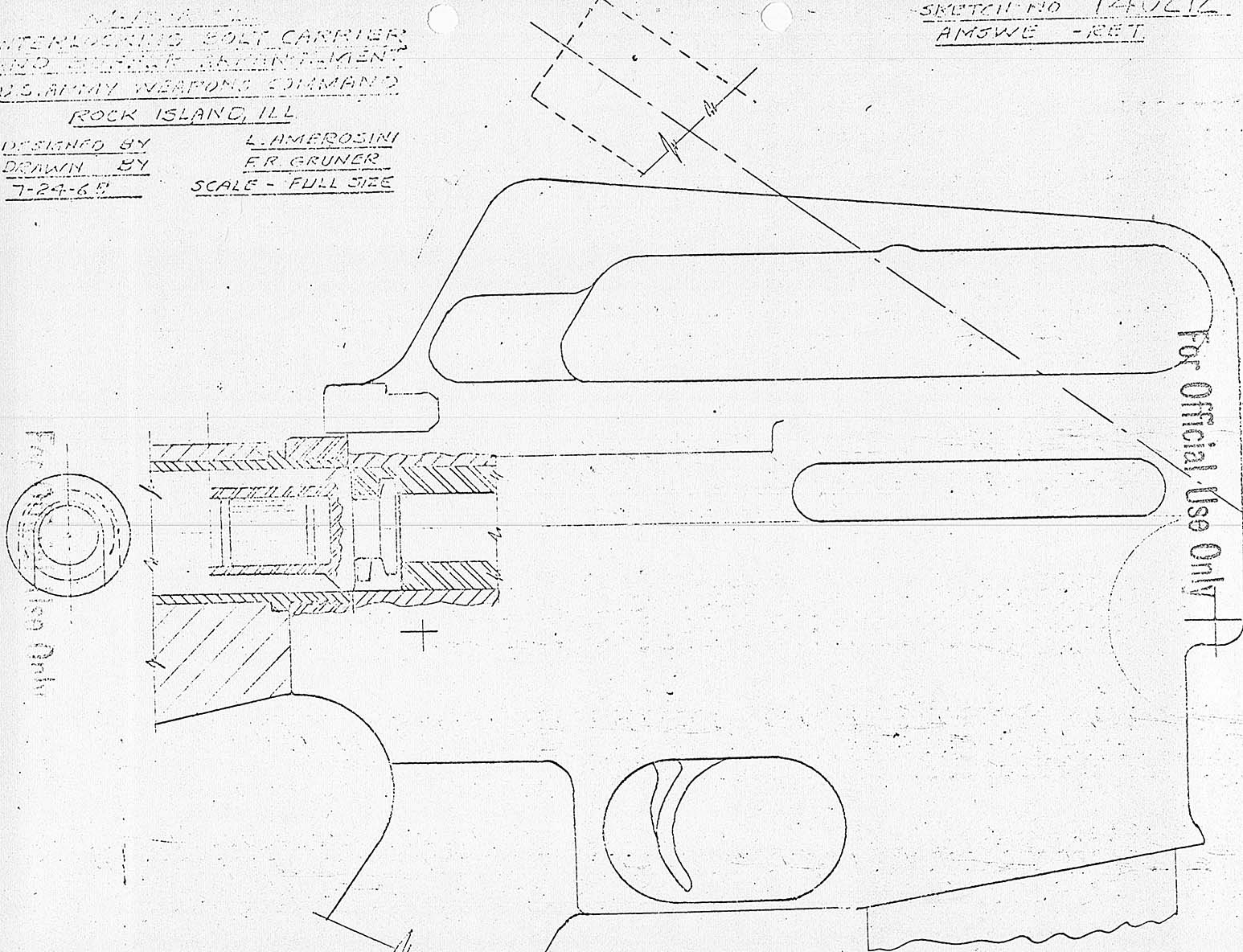
At the moment of extraction, the bolt carrier is slowed down by shock to launch the bolt and the cartridge, and also by the extraction force. Some delayed recovery of this loss of speed is furnished by the blow back internal pressure of the chamber. However, the buffer, or better in the redesigned buffer, its center of gravity represented by the damping masselets continues alone against the main recoil spring and does not participate to the effort of extraction. In other words, the total mass launched in recoil is not available at the critical moment of extraction, which increases the sensitivity to the extraction force and the directly affect the cyclic rate.

The objective of this project is to design a join between bolt carrier and buffer which will open the way to full utilization of the masses in movement,

INTERLOCKING BOLT CARRIER
AND BUFFER ARRANGEMENT
U.S. ARMY WEAPONS COMMAND
ROCK ISLAND, ILL

DESIGNED BY L. AMBROSINI
DRAWN BY F.R. GRUNER
7-24-65 SCALE - FULL SIZE

SKETCH NO 1440212
AMSWE -RET.



while also allowing the actual opening of the rifle. The design of such join is attached.

This joint will be designed, incorporated in one rifle and tested to prove that no inconvenience or unsuspected effect will arise by such joining feature. The objective is to prove that the join is feasible without inconvenience.

There will be no change in this project on the inside of the buffer, as the masselets will move on their own as before. The task to avoid their free movement will be in a separate project.

e. Buffer With Full Mass Utilization

If the joint between buffer and bolt carrier described in the preceding task proves successful, the way is open to a full utilization of all masses for extraction purpose, including the floating mass used to stop the bolt rebound at return in battery. Also, eventually by use of tungsten alloys in the buffer instead of steel, no high stresses existing inside the buffer, it is possible to increase the total moving mass of the bolt system, which is a general rule to improve operational stability of a weapon. We are speaking here of a fraction of a pound, for which calculations show interesting results. More power from the gas system is available, due to the ratio of 309 to 1 between muzzle power and bolt system power, without effecting bullet velocity. Of course an increase in weight has to be made in case of no other alternative.

To proceed into this task some preliminary results should already be known from the preceding tasks, as well as from the kinematic study of BRL. So it is not possible to give hereby a sketch of the buffer modification, but the objective of this project should follow these guide lines.

Use of classical high rate spring mounted on the buffer to end the recoil stroke. Answer the question about the need of damping on this effect and design the modification consequently.

The total mass of the buffer, including the floating mass will walk together with the bolt carrier to launch the bolt and the fired cartridge case, and to overcome the extraction force. Such effect can be obtained by a spring able to support the acceleration force on the floating mass and maintain the mass at the back end of the buffer case. It is now kept at the front end by the recoil acceleration. At return in battery, the force of deceleration being quite higher that the force of recoil acceleration, the spring will collapse and the mass will impact on the port end of the buffer case, stopping the bolt rebound. Adequate damping mean will be used to avoid secondary effects. The effect can be both calculated and measured.

f. Gas Piston Outside Bolt System

Basically the use of gas flowing to the region of the bolt system was introduced in automatic weapons for weight reduction and increase of cyclic rate, due to the high velocity of the gas. The second reason does not exist for a personal weapon as a rifle, but weight reduction is important. However, the method how it was used has brought a number of problems, particularly to the M-16 Rifle, which has been enumerated in this study.

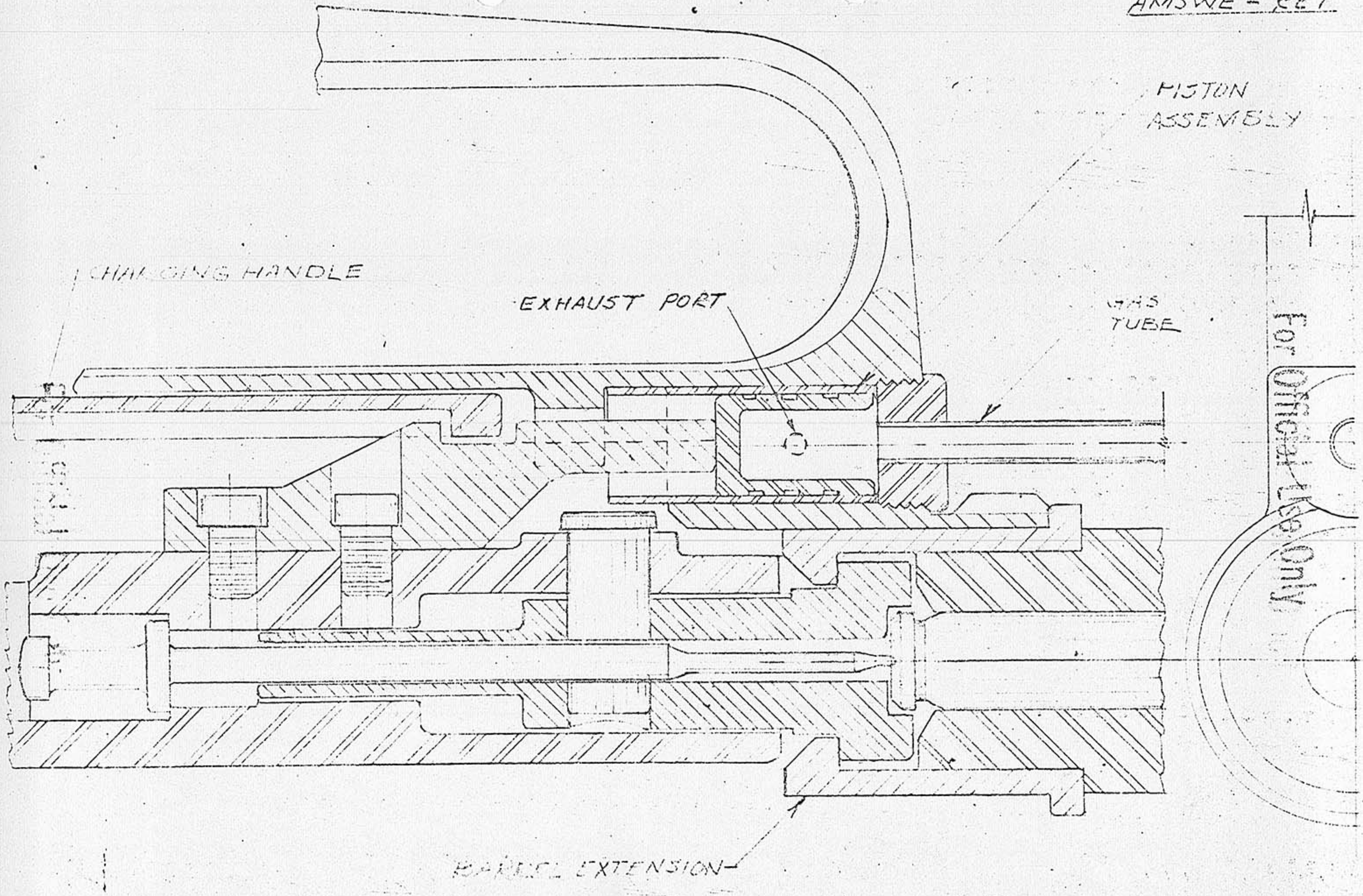
It is possible to modify the system mounting a gas piston of equivalent working section axially with the gas tube and pushing the bolt carrier through a modified key. Such a modification is mechanically simple, with no change in the weight or external appearance of the weapon, but the changes in physical characteristic are interesting. It does not have the added weight or the dynamic complication of the use of a push bar. The sketch hereby shows such a design modification. It needs more design refinements, but it shows the principle and the following physical system changes can be deducted.

1. No more fouling by the gas inside the bolt system, as there is no gas injection.

2. No gas leak between gas tube and key.

3. The reaction of or the launching of the bolt carrier is against the receiver and not the head of the cartridge case. So no ramming or deformation of the cartridge case can occur.

SKETCH NO
AMSWE - RET



U.S. ARMY WEAPONS COMMAND
ROCK ISLAND, ILL.

M-16 RIFLE
PISTON & GAS CYLINDER
ARRANGEMENT

DESIGNED BY L. AMBROSINI
DRAWN BY E.R. GRUNER

4. Straight jet of the gas against the piston.

If the project to reduce the cartridge pinching by changing the brass hardness profile succeeds, the cartridge case can eject as soon as the bolt unlocks the chamber. In this case, use of the blow back effect of the internal pressure in the chamber can be utilized, the bolt can be launched by the cartridge case and the bolt carrier needs less initial velocity.

5. Decrease effort on the cam groove for extraction, and use of the internal cavity for interface between bolt carrier and bolt, with no effort on the cam pin at chambering. This region is a mechanical weak portion of the rifle.

The objective of this project is to study, design, construct and test this modification as a feasibility project and to furnish a complete comparison report between the two alternatives.

CONCLUSION

The preceding program extends to a series of tests of actual hardware and a series of modifications for product improvement. Concerning the first, the cost of the program will be largely justified, not only for potential product improvements, but eventually recording its cost by better knowledge of the hardware and follow-on improvement of the acceptance specification. Concerning the design modifications, it can be noted that they are small, even if some are important. It can also be noted that some are overlapping, but until their parameters are known, no final intelligent decision can be made. It is difficult to predict their success, as in any engineering project with data still based on a few samples, but it is worth at least to try.

M-16 Rifle Technical Data

The following data are average measured or specified data:

Individual Weight -	Buffer Assembly, Old Design	57.0 gms
	Buffer Assembly, New Design	147.5 gms
	Recoil Main Spring	59.1 gms
	Bolt Assembly With Cam Pin	51.4 gms
	Bolt Carrier Assembly	275.3 gms
	Round, Ball Prop & Ball Proj	11.7 gms
	Round, Extruded Prop & Tracer Proj	11.5 gms
	Cartridge Case Fired	6.2 gms
	Projectile, Ball (55 ± 1 gr)	3.56 gms
	Projectile, Traver (53 ± 1 gr)	3.43 gms
Bolt System Weight -	Return in Battery, New Buffer Ball Proj & Prop (Round +½ Spring)	515.5 gms
	On Recoil, Same Condition	510.0 gms
Main Spring -	Compressed Length of 4.415 in, Full Recoil	4,944.2 gms
	Compressed Length of 8.190 in, in Battery	2,630.8 gms +226.8 gms
	Spring Rate	241.3 gm/cm
	Compressed Energy Available	36,175 gm.cm ±3,250 gm.cm

Propellant	IMR 8208M Specific Impetus	100 $\frac{kg.m}{m}$
	WC 846 Specific Impetus	106 $\frac{kg.m}{m}$
	IMR 8208M Load in Cartridge	1.64 gm
	WC 846 Load in Cartridge	1.83 gm
	IMR 8208 Impetus in Round	164 Kg.m
	WC 846 Impetus in Round	194 Kg.m
Velocity	Bullet Velocity (3250 $\pm$ 40 f/s)	990.6 m/sec
	Bolt Carrier Peak Recoil Velocity Measured by FA	5.0 m/sec
	Loss of Velocity by Bolt Carrier to Launch by Shock Bolt and Cartridge (Without Friction Force or Blow Back Effects)	17.3%
	Remaining Bolt Carrier Velocity	4.13 m/sec
Momentum	Ball Projectile Momentum	359.1 gm.sec
	Peak Momentum of Bolt Carrier at Recoil	140.2 gm.sec
	Peak Momentum of Buffer (new) at Recoil	75.1 gm.sec
	Total Impulse By Gas Actuator	225.3 gm.sec
Cyclic Rate	Specified	750 rounds/min $\pm$100 rounds/min
	Time Between Firing	80 millisec
Energy	Muzzle Energy, Ball Proj.	177.9 Kg.m/round
	Peak Recoil Energy, Bolt Carrier Plus Buffer + ½ Spring	.575 Kg.m/round
Power	Muzzle Power (at 750 rounds/min)	29.6 HP
	Peak Recoil System Energy	.096 HP
	Ratio of Powers	309 to 1

MEMORANDUM FOR RECORD

SUBJECT: A Study in Ammunition Extraction and Chambering in the M16A1 Rifle System Conducted at Frankford Arsenal 5 to 7 June 1968.

The object of this study was to determine whether the forward thrust of the bolt during unlocking makes a significant contribution to extraction force and to obtain an estimate of the time relationship existing between the chamber pressure and the bolt pressure.

Bolt Forward Thrust Evaluation

The basic procedure consisted of measuring the change in head position of the cartridge case relative to the barrel and evaluating this change in terms of force by comparing it with the deflection obtained by statically pressing cartridge cases into a chamber.

A cartridge was chambered from the magazine with an extractorless bolt by means of the manual charging handle. The location of the case relative to the barrel locking lugs was obtained by measuring the space from the inside barrel locking lug surface to the case head. The cartridge was fired and the same dimension remeasured. The procedure was repeated with a second cartridge but with the gas transmission system plugged. Thus the effect of forward thrust exists in the difference obtained in change of head position relative to the barrel. The measurements recorded are shown in Figure 1 and listed in Table I.

The difference in head location between firings with and without the gas tubes plugged is relatable to force magnitude by comparing it with the force-deflection curve obtained by statically compressing a cartridge case into a chamber. Figure 2 contains three typical curves. One curve is for an unused cartridge case where the case is supported by the shoulder taper. Two curves are for cases with the shoulder removed where the case is supported by the body taper. Approximately one-eighth of an inch rearward of the shoulder was removed to insure that no support was given the case by the shoulder taper in the rifle chamber. One curve is for a fired case and the other for an unfired case. The tests were repeated for both cases and chamber conditioned to temperatures of 100°F, 200°F, and 300°F. No significant change in the curves shown in Figure 2 occurred.

TABLE I

Head Position Relative to Barrel Locking Lug

Cartridge Case Number	Rifle Number	(A) Bolt Locking Lug Length	(B) Bolt Case Head Recess	(C) Barrel Locking Space Length	(D) Case Head Location After Chambering	(E) Case Head Location After Firing	(F) Case Head Location After Firing Without Gun Tube
1.	1	.280	.127	.289	.1615	.1590	-
2.	1	.280	.127	.289	.1610	.1575	-
3.	1	.280	.127	.289	.1615	.1580	-
4.	1	.280	.127	.289	.1605	.1570	-
5.	1	.280	.127	.289	.1610	.1575	-
6.	1	.280	.127	.289	.1610	-	.1540
7.	1	.280	.127	.289	.1610	-	.1545
8.	1	.280	.127	.289	.1610	-	.1545
9.	1	.280	.127	.289	.1615	-	.1550
10.	1	.280	.127	.289	.1620	-	.1545
11.	2	.280	.127	.285	.1610	.1585	-
12.	2	.280	.127	.285	.1600	.1545	-
13.	2	.280	.127	.285	.1610	.1590	-
14.	2	.280	.127	.285	.1605	.1590	-
15.	2	.280	.127	.285	.1600	.1575	-
16.	2	.280	.127	.285	.1600	-	.1545
17.	2	.280	.127	.285	.1605	-	.1545
18.	2	.280	.127	.285	.1610	-	.1545
19.	2	.280	.127	.285	.1605	-	.1545
20	2	.280	.127	.285	.1605	-	.1545

Numbers 1 thru 10 fired in new rifle; and numbers 11 thru 20 fired in old rifle.

For Official Use Only

An estimate of the temperature rise in the cartridge case sidewall was obtained by drilling a small hole in the chamber and placing a high response thermocouple against the case. The temperature recorded was approximately 300°F.

A static measurement of the force required to extract the cartridge case was made by pulling the case from the chamber with a spring gage. This was done for both pressurized and unpressurized bolt conditions to determine if the difference was measurable. The results are given in Table II.

The conclusion from the above tests is that the bolt does produce a forward thrust on the cartridge case just prior to unlocking. No explanation is made at this time for the unexpected recording of higher static extraction force for the unpressurized bolt system as compared with the pressurized system as well as for the relatively low value for both.

Bolt Pressure-Chamber Pressure Time Relationship

Frankford Arsenal developed techniques for measuring chamber pressure and port pressure simultaneously in a test barrel and for measuring bolt pressure on a prototype rifle, but has yet to develop a technique for measuring all three simultaneously in a prototype weapon. Therefore, an indirect procedure is required. First the chamber and port pressures are measured in a test barrel with projectile muzzle exit indicated on the record. The record is continued to the point in time where the pressures become zero. This permits an estimate to be made of the pressure existing in the case at the time of extraction. Second, the bolt pressure is recorded with projectile muzzle exit indicated on it. Thus, the common projectile muzzle exit point on both records permits the complete time sequence to be established. Figures 3 through 8 are such records. Figures 3, 4, and 5 are for WC-846 ball type propellant loaded cartridges; and Figures 6, 7, and 8 are for IMR-8208M extruded type propellant loaded cartridges. Shown on Figure 3 is the bolt pressure record which is initiated by a signal from the firing pin and continues to gas tube separation from the bolt carrier. The first part of this record, the horizontal line, contains a change in record intensity signifying projectile muzzle exit. Since muzzle exit and initiation of pressure rise in the bolt occur very close in time, the second record was made simultaneously with the first one to expand in time the initial portion of the bolt pressure curve to clearly indicate the time existing between projectile muzzle exit and bolt pressure initiation. This time is indicated by a change in intensity of the line and is indicated by the .11 ms dimension. This portion of the record was further expanded on second recording shown in Figure 4 because of difficulty in determining the exact instant of pressure rise. The first curve is the normal bolt pressure-time record while the second curve is an expansion of the record from projectile muzzle exit to

For Official Use Only

TABLE II

Case Extraction Force

Cartridge Case Number	Rifle Number	(G) Case Static Extraction Force With ~~Gun~~ GAS Tube (lb)	(G) Case Static Extraction Force Without ~~Gun~~ GAS Tube (lb)
1.	1	4	-
2.	1	5.5	-
3.	1	4.5	-
4.	1	4.75	-
5.	1	5	-
6.	1	-	23
7.	1	-	24
8.	1	-	22.5
9.	1	-	21
10.	1	-	21
11.	2	3	-
12.	2	3	-
13.	2	2.5	-
14.	2	3	-
15.	2	3	-
16.	2	-	4
17.	2	-	3.5
18.	2	-	4
19.	2	-	4
20.	2	-	4.5

Numbers 1 thru 10 fired in new rifle having .009 clearance between bolt lug and chamber space.

Numbers 11 thru 20 fired in old rifle having .005 clearance between bolt lug and chamber space and 10,000 rounds fired in it.

For Official Use Only

bolt pressure rise. The time is now clearly indicated to be .08 ms from projectile muzzle exit to the beginning of pressure rise in the bolt. Figure 5 contains chamber and port pressure records. A change in intensity indicates projectile muzzle exit. From these three records, the times in Table III are observed. Figures 6 through 8 are the same type of records for cartridges loaded with IMR-8208M propellant.

TABLE III

Time of Events-Milliseconds

	WC-846	IMR-8208M
Primer Struck	0	0
Port Pressure Begins	1.05	0.85
Muzzle Exit	1.25	1.08
Muzzle Exit to Bolt Pressure	0.08	0.07
From Beginning of Record to Bolt Pressure	1.16	1.12
Port to Bolt Pressure	0.28	0.30

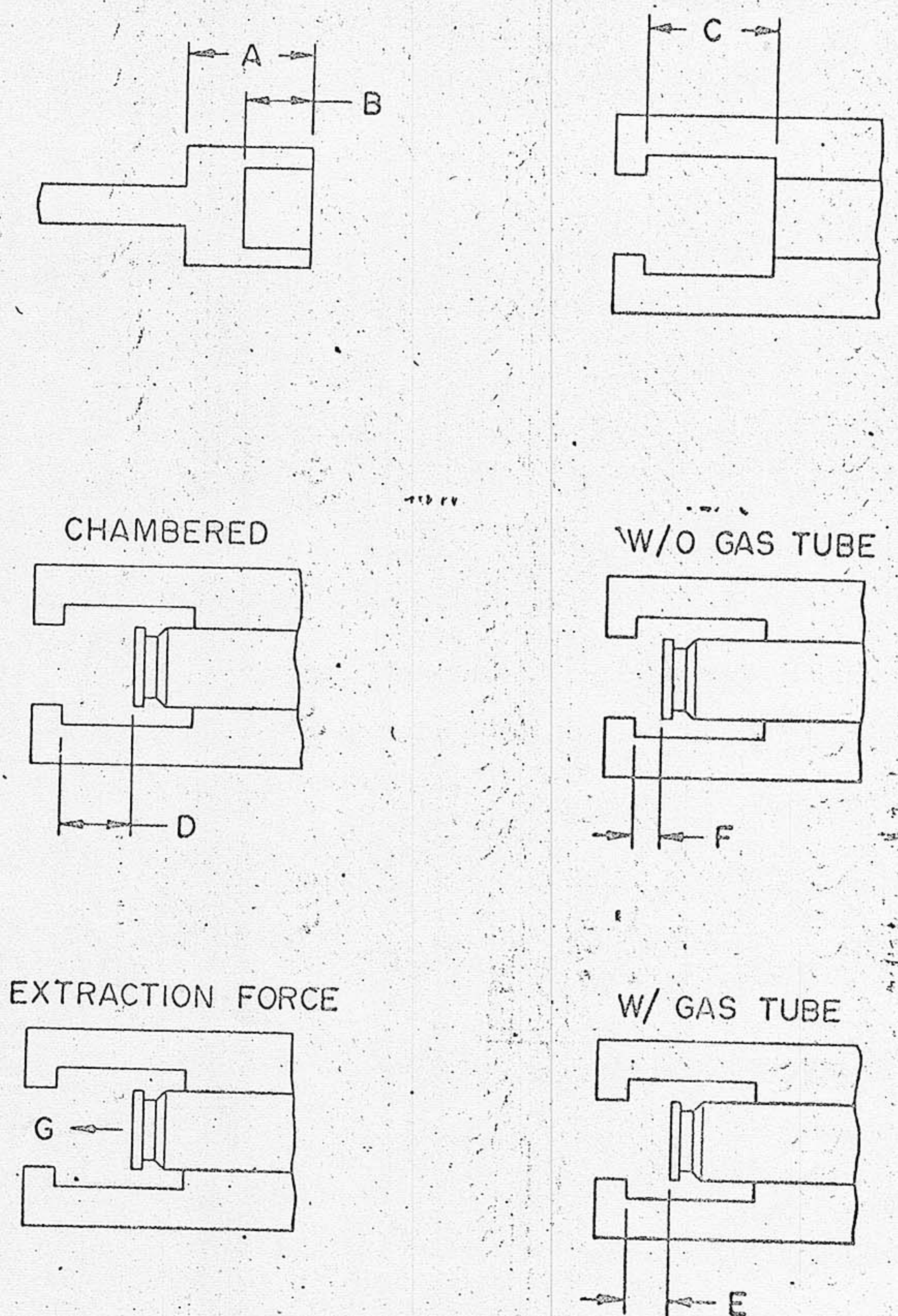
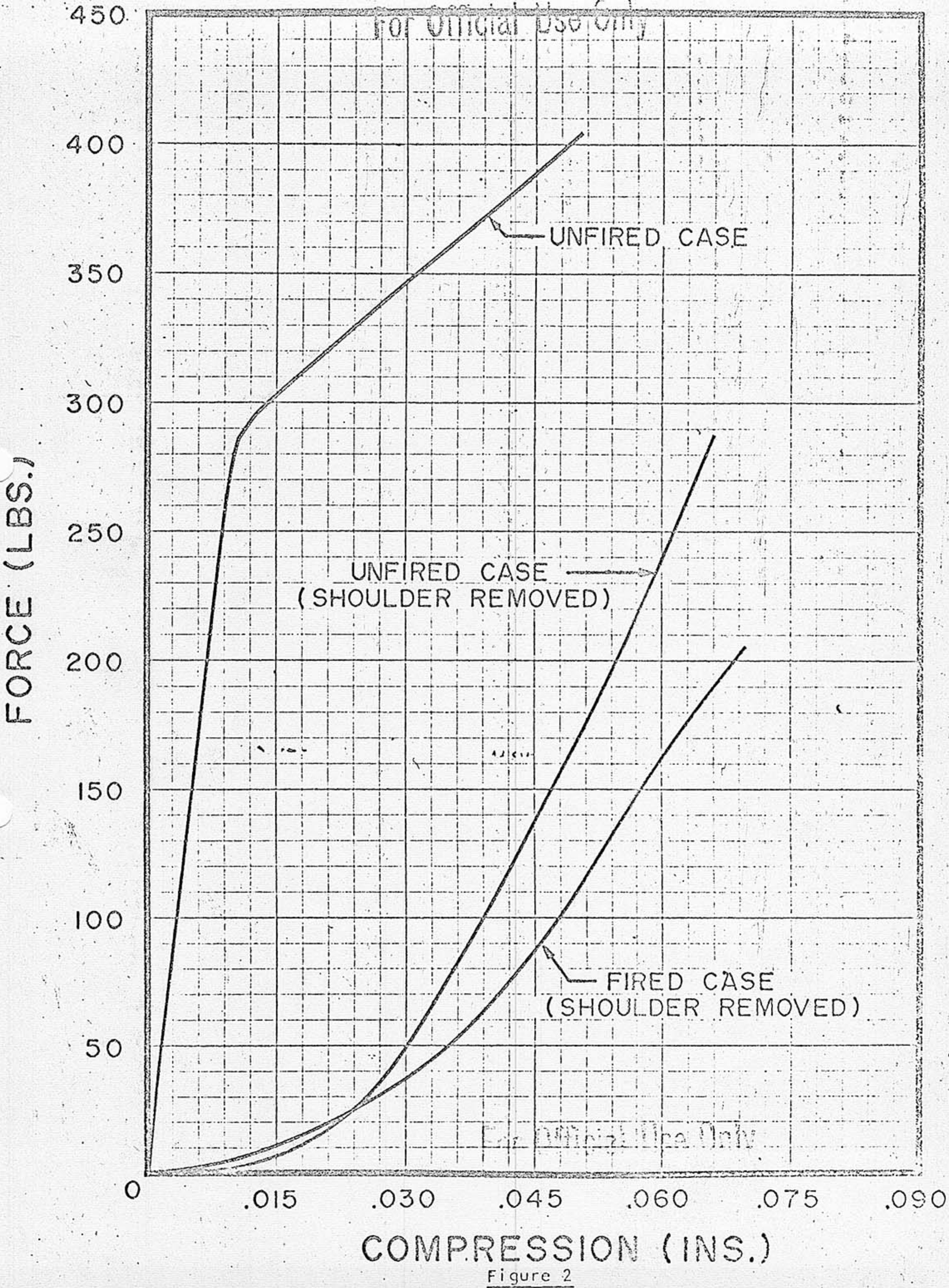


Figure 1



For Official Use Only
FORCE (LBS.)
450
400
350
300
250
200
150
100
50
0
.015
.030
.045
.060
.075
.090
UNFIRED CASE
UNFIRED CASE
(SHOULDER REMOVED)
FIRED CASE
(SHOULDER REMOVED)
COMPRESSION (INS.)

Figure 2

LC12304 WC846

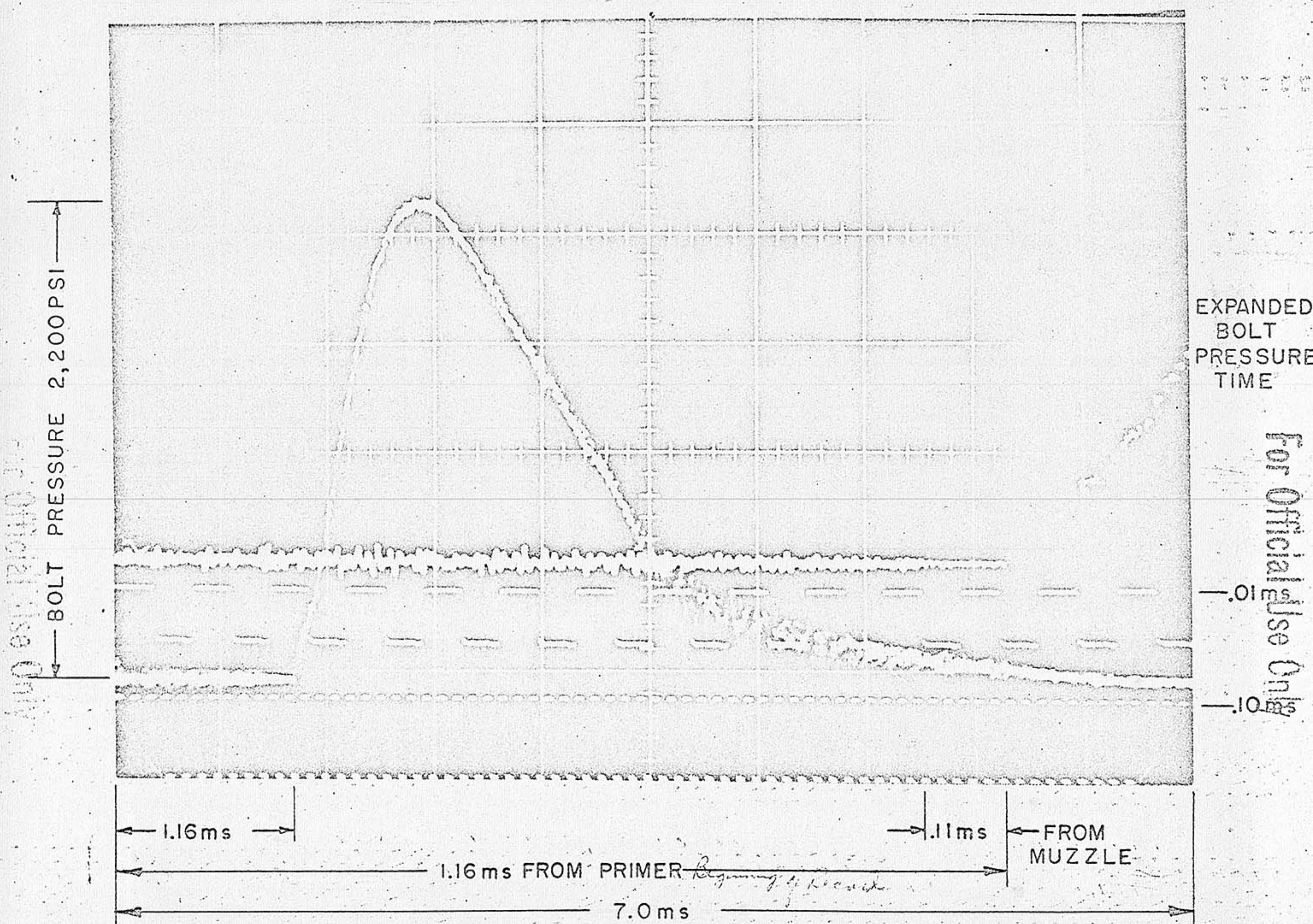


Figure 3.

LC12304 WC846

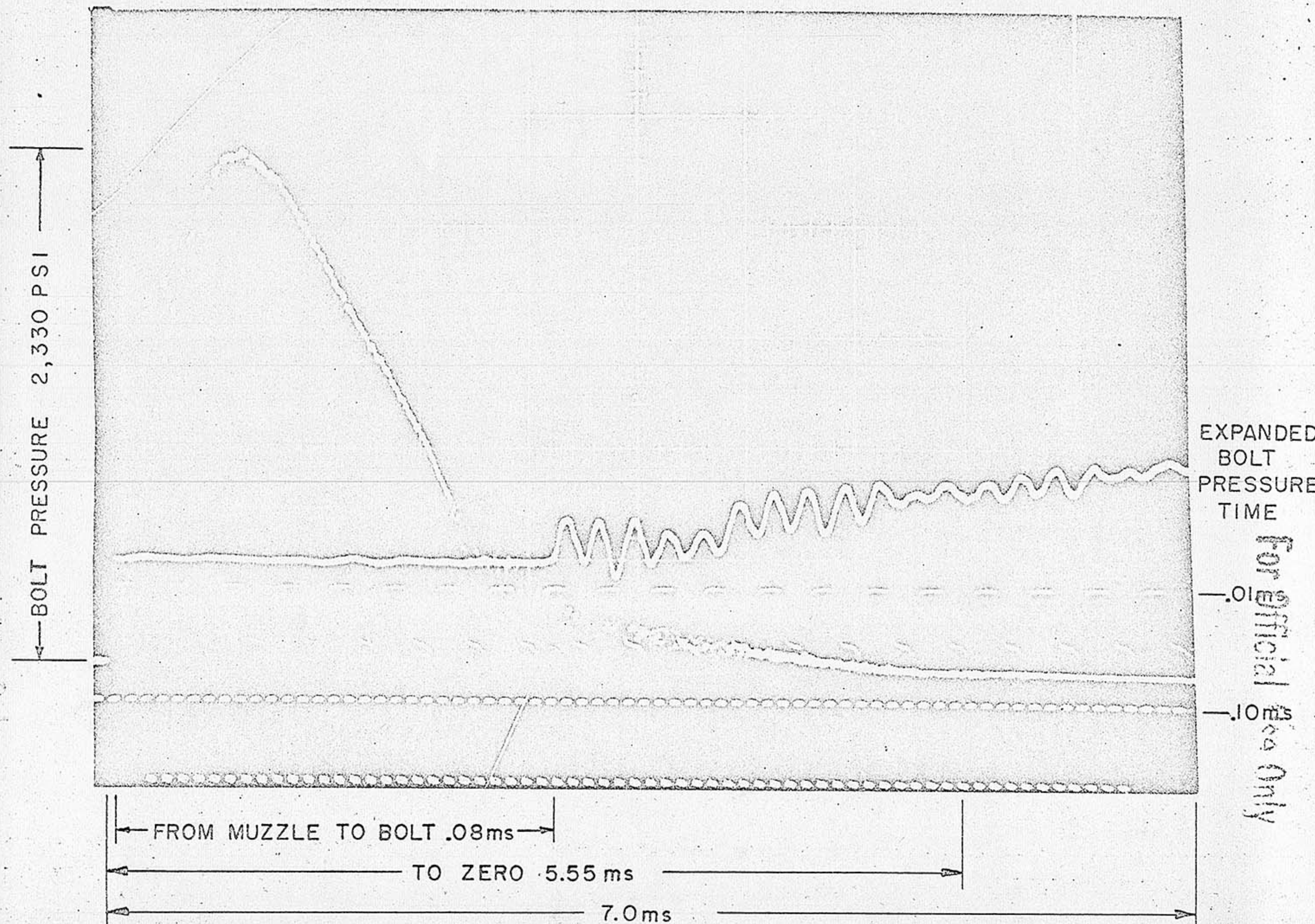
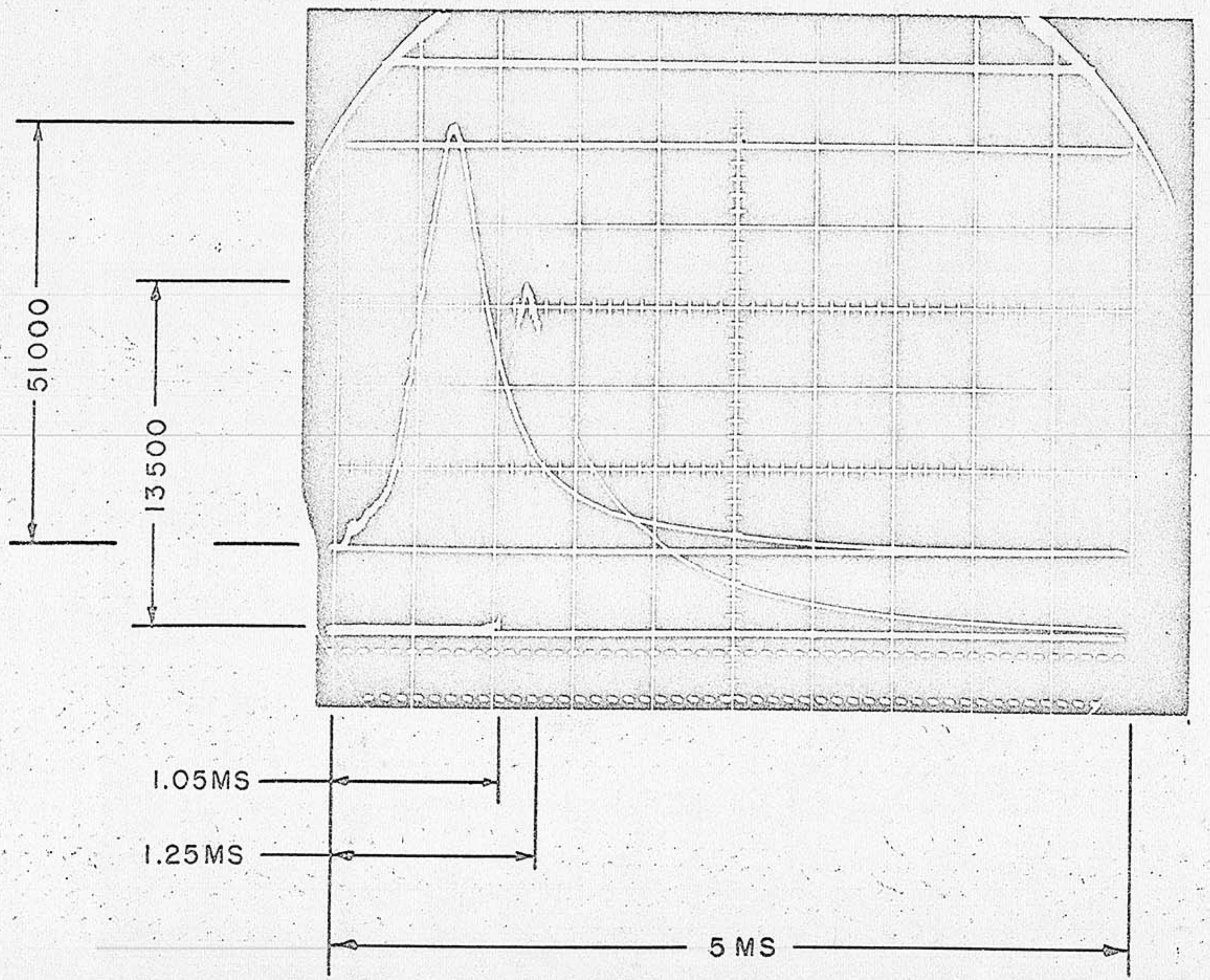


Figure 4.

TW 18224 WC846



T /-18048 IMR820 M

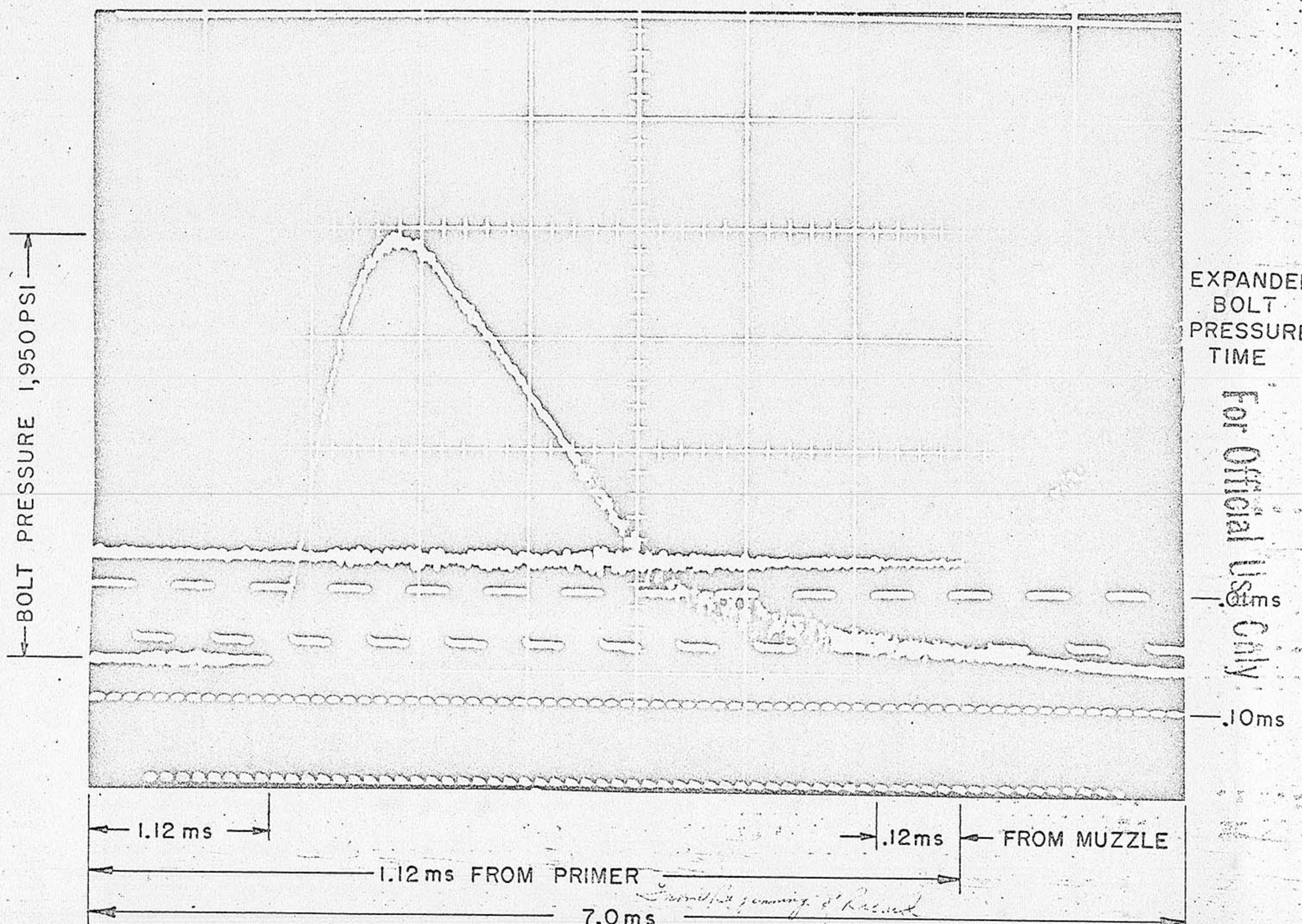


Figure 6.

TW 18048 .IMR8208M

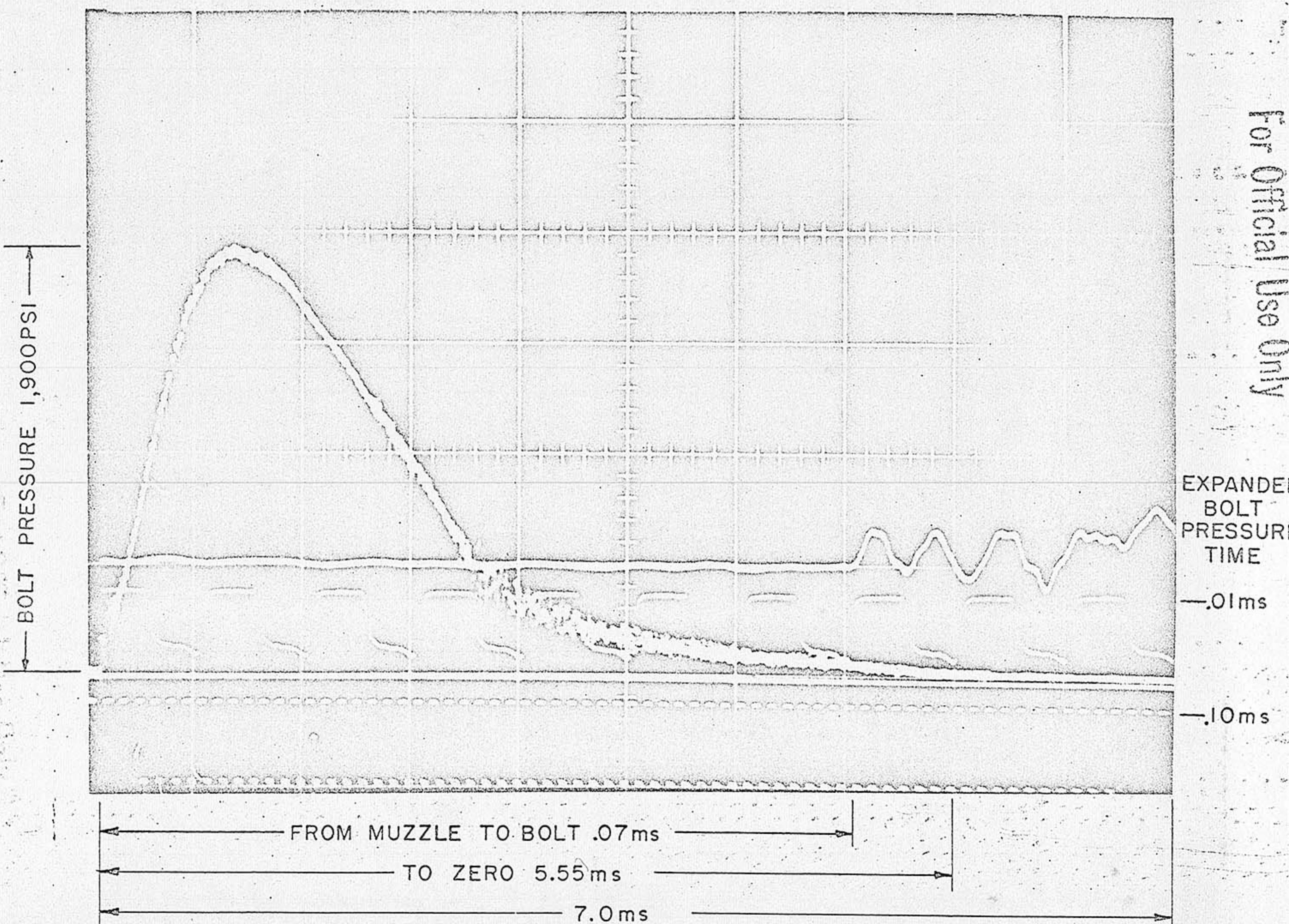


Figure 7

TW18205 IMR 8208M

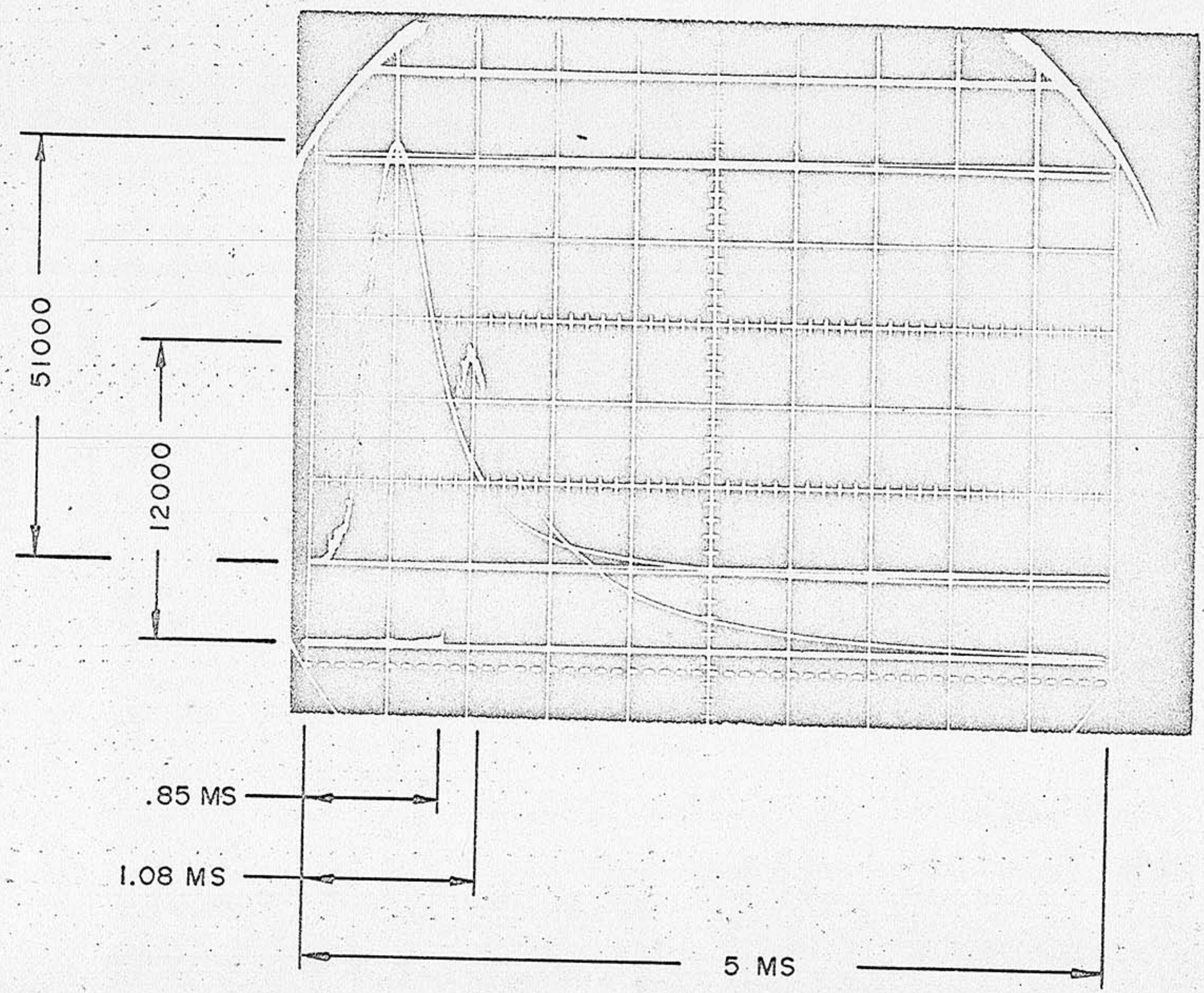


Figure 8

11 July 1968

MEMORANDUM FOR RECORD

SUBJECT: Study of After Firing Clearance Between Rifle Chamber and Cartridge Case for Rammed and Unrammed Conditions

The object of this study was to determine the clearance between the cartridge case and chamber at several locations in the chamber for cases rammed and unrammed. Rough calculations were made to provide an estimate of the approximate internal pressure required to take up the clearance between chamber and cartridge.

Firing procedure consisted of firing six 5.56mm cartridges in an M16 rifle. Half of the cartridges were fired with the gas tube operational and the other half with the gas tube disconnected. The extractor was removed and the fired cases were extracted by hand to prevent damage to them.

A mold was made of the M16 chamber before firing. The base of the chamber was used as the reference point for all measurements. Diameters were measured every one quarter inches. The corresponding points on the cartridge were located by measuring the distance the cartridge protruded from the base of the chamber before and after firing to find the location of the diameter on the case which corresponded to the chamber diameter. All measurements were made on a Jones & Lamson Epic 30 Comparator and Measuring Machine. The results of the measurements and calculations are given in Tables I, II, and III.

Figure 1 shows the location of the chamber diameters measured.

Figure 2 shows the location of the two dimensions, A and B, measured before and after firing to determine corresponding chamber and case diameters. Thus, a location of a diameter on the case after firing which corresponded to a chamber diameter was obtained by calculating C (C = B-A) and adding this to "X" (Figure 1).

Table I contains a tabulation of the measured data. The first column identifies chamber location, and the second column the chamber diameter at this point. Columns three and six list the diameters of the cartridges before they were fired at locations corresponding to these chamber locations. Columns four and seven list the diameters of the cartridge case at the same locations after they were fired. Columns five and eight contain the difference between the chamber diameter and the case diameter (column 2 minus column 4). Column nine is the difference (column 8 minus column 5) between the clearance obtained after firing for rammed and unrammed cases (with and without gas tube connected).

Table II contains tabulations of location dimensions A, B, and C. The difference columns in the Dimension C tabulations reflect the effect of ramming.

Table III contains the results of calculations made to obtain an estimate of the pressures required to have the case take up the clearances existing after firing between the case and chamber wall. The two figures given in the case clearance column under each heading are maximum and minimum clearance determined by tests on three cartridges. Pressures were calculated for both maximum and minimum clearances.

C. C. [illegible]
Director
Ammo Dev & Engr Labs

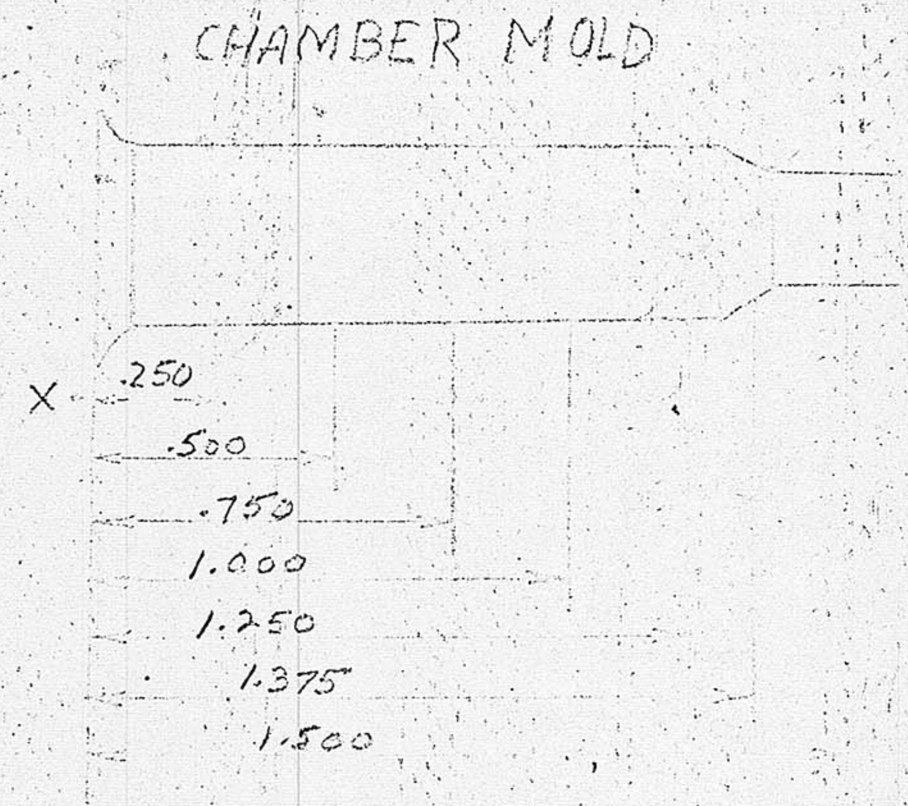


FIGURE 1

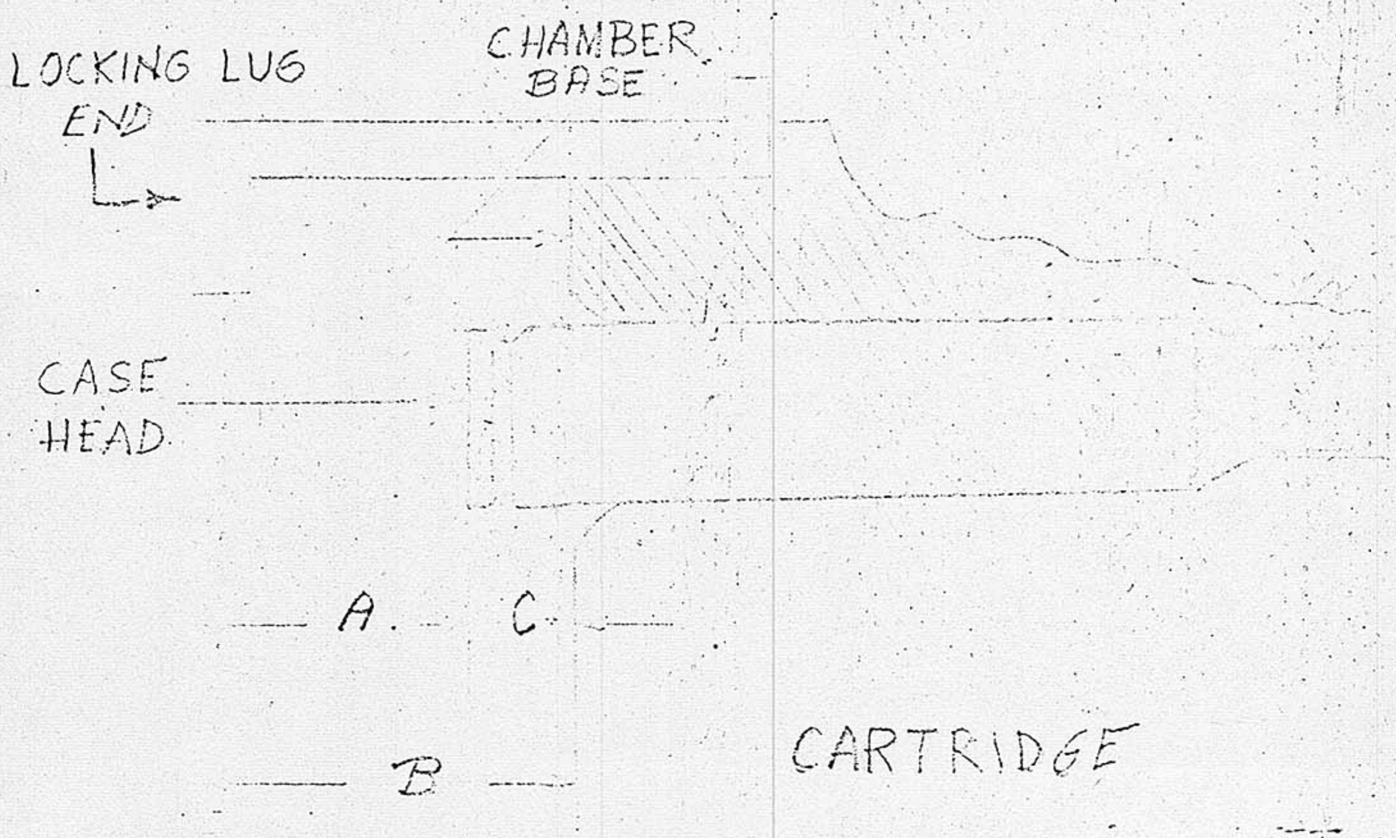


FIGURE 2

TABLE I

CHAMBER AND CARTRIDGE DIAMETERS

Chamber		Cartridge WGT			Cartridge WOGT			Difference
Location	Diameter	Before	After	Diff	Before	After	Diff	WGT - WOGT
1	2	3	4	5	6	7	8	9
.250	.3760	.3700	.3757	.0003	.3700	.3752	.0008	.0005
		.3701	.3757	.0003	.3700	.3751	.0009	.0006
		.3700	.3755	.0005	.3700	.3752	.0008	.0003
.500	.3710	.3658	.3704	.0006	.3668	.3702	.0008	.0002
		.3665	.3706	.0004	.3669	.3700	.0010	.0006
		.3658	.3704	.0006	.3662	.3704	.0006	.0000
.750	.3665	.3618	.3660	.0005	.3635	.3661	.0004	-.0001
		.3625	.3661	.0004	.3626	.3656	.0009	.0005
		.3618	.3660	.0005	.3620	.3657	.0008	.0003
1.00	.3622	.3564	.3618	.0004	.3578	.3618	.0004	.0000
		.3574	.3621	.0001	.3566	.3625	-.0003	-.0004
		.3570	.3618	.0004	.3564	.3618	.0004	.0000
1.250	.3578	.3512	.3576	.0002	.3512	.3577	.0001	-.0001
		.3517	.3575	.0003	.3513	.3587	-.0009	-.0012
		.3515	.3580	-.0002	.3515	.3581	-.0003	-.0001
1.375	.2943	.2970	.2980	-.0037	.2973	.2973	-.0030	.0007
		.2967	.2970	-.0027	.2972	.2975	-.0032	-.0005
1.500	.2564	.2483	.2550	.0014	.2484	.2558	.0006	-.0008
		.2484	.2570	-.0006	.2486	.2507	-.0003	.0003
		.2483	.2552	.0012	.2482	.2557	.0007	-.0005

Notes: WGT = with gas tube
WOGT = without gas tube
Col 5 = Column 2 - Column 4
Col 8 = Column 2 - Column 7
Col 9 = Column 8 - Column 5

TABLE II

RELATIVE CHAMBER AND CASE HEAD LOCATIONS

Dimension A

Cartridge Head to End Locking Lug

Before Firing		After Firing	
With Gun Tube	Without Gun Tube	With Gun Tube	Without Gun Tube
.375	.376	.372	.370
.376	.375	.370	.370
.376	.375	.373	.371

Dimension B

Base of Chamber to End Locking Lug

0.502

Dimension C (= B-A)

Chamber Base to Case Head

With Gun Tube			Without Gun Tube		
Before	After	Difference	Before	After	Difference
.127	.130	.003	.126	.132	.006
.126	.132	.006	.127	.132	.005
.126	.129	.003	.127	.131	.004

6 June 1968

TEST AND RELIABILITY EVALUATION BRANCH REPORT

SUBJECT:

Instrumentation for measurement of Cartridge Extraction Force in M16A1 Rifle.

ITEMS TESTED:

Six barrels with conditions as follows:

Barrel S.N.	Condition
19081	New - No Chrome Plate
19092	New - No Chrome Plate
19087	New - Phosphate Coat
17238	Used - Pitted Chamber
17233	Used - Pitted Chamber
17235	Used - Pitted Chamber

OBJECT:

To develop a method for measuring cartridge extraction force during firing.

PROCEDURE AND RESULTS:

A single small electric resistance strain gage was mounted on each of three extractors, Figure 1. The strain gages were B.L.H. Type FAE-18-1258-L compensated for use on steel. They were bonded with Eastman 910 cement.

A standard M16A1 rifle carrier, Bolt and Upper Receiver were modified to permit normal action during firing without damage to the strain gage and lead wires, Figure 2.

Test data was recorded on polaroid film with a camera mounted on a Tektronix type 549 oscilloscope using a type Q carrier amplifier plug-in unit. The system frequency response is dc to 6KHz with a rise time of 70 microseconds.

Firing tests were conducted using both automatic and single shot modes of fire. All rounds were fired with ammunition Lot No. 12631. Results of tests are shown in Tables I, II, III and IV.

Typical force time analogs are shown in Figure 3.

TABLE III

PRESSURE TO TAKE UP CLEARANCE

Chamber Location	Case Wall Thickness	Case Outside Radius	Case Inside Radius	Case Clearance With Gun Tube	Case Clearance Without Gun Tube	Pressure With Gun Tube	Pressure Without Gun Tube
.250	.0270	.1874	.1604	.0003	.0008	2100	5500
				.0005	.0009	3400	6200
.500	.0145	.1849	.1704	.0004	.0006	1400	2200
				.0006	.001	2200	3600
.750	.0105	.1824	.1719	.0004	.0004	1100	1100
				.0005	.0009	1300	2400
1.000	.0086	.1799	.1713	.0001	.0004	200	900
				.0004	-.0003	900	-
1.250	.0074	.1774	.1700	.0002	.0001	400	200
				-.0002	-.0009	-	-

$$P_c = \frac{E}{c}\left(\frac{1}{\frac{b^2 + c^2}{c^2 - b^2} - v}\right) u$$

where

E = Modulus of elasticity of brass
c = Outer radius of case
b = Inner radius of case
v = Poisson's ratio
u = Displacement of radius
P_c = Shrink fit pressure

Test Report 6 June 1968

DISCUSSION OF RESULTS:

Tables I and II show values of peak tension load on the extractor. The primary value of this data is to show the variation in extractor force from round to round in each mode of fire. It is useful for making comparisons. Note that the peak force is less for automatic fire than for single shot fire.

The data in Table III shows extractor momentum in gram seconds. This was determined using conventional procedure - integrating the area enclosed by the force (Load) time curve and multiplying by unit time and unit load. This data indicate the quantity of energy the gas system must provide the bolt assembly for extracting the cartridge.

Static extraction force was obtained by filing off a portion of the cartridge rim so that the cartridge remained chambered after firing. A metal rod was inserted in the bore against the cartridge. The force required to dislodge the cartridge was measured with a calibrated force gage. This data is contained in Table IV. The purpose of this test was to find out if there was a significant difference in static extraction force for the new and used barrels and if so, could this data be related to the dynamic extraction force.

During static calibration of the instrumented extractors, it was found that cartridge rim shear occurred at approximately 260 pounds.

Four rounds were fired with the gas tube disabled to check for undesirable signed output from the strain gage. None have occurred.

Further effort should be made to determine extractor momentum at force levels which cause cartridge rim sheer to occur.

CONCLUSIONS:

It is believed that a satisfactory initial method has been developed for measuring the dynamic extraction force of the M16A1 Rifle. It is also believed that this method will provide a useful tool for evaluating the gas system of the M16A1 rifle.

This data indicates that a decrease in the slope and magnitude of the force time curve during cartridge extraction might reduce the frequency of cartridge rim sheer under adverse operating conditions.

James C. Hanson

TABLE I

SUMMARY OF CARTRIDGE EXTRACTION FORCES - M16A1 RIFLE
FIRING TESTS WITH EXTRACTOR NO. 1

NEW BARREL S.N. 19081 — FIRING MODE

Single Shot RD No	Single Shot Force Lbs	Automatic RD No	Automatic Force Lbs
1	237	1	190
2	---	2	175
3	320	3	260
4	---	4	250
5	240	5	---
AVG	265		220

NEW BARREL S.N. 19092 — FIRING MODE

Single Shot RD No	Single Shot Force Lbs	Automatic RD No	Automatic Force Lbs
1	215	1	145
2	185	2	140
3	185	3	150
4	170	4	175
5	215	5	---
AVG	195		150

USED BARREL PITTED CHAMBER S.N. 17288 — FIRING MODE

Single Shot RD No	Single Shot Force Lbs	Automatic Rd No	Automatic Force Lbs
1	380	1	380
2	400	2	400
3	380	3	380
4	360	4	360
5	380	5	380
AVG	380		350

USED BARREL PITTED CHAMBER S.N. 17235 — FIRING MODE

Single Shot RD No	Single Shot Force Lbs	Automatic RD No	Automatic Force Lbs
1	400	1	360
2	360	2	280
3	380	3	290
4	380	4	---
5	340	5	---
AVG	365		310

NEW BARREL PHOSPHATE COAT S.N. 16967 — FIRING MODE

Single Shot RD No	Single Shot Force Lbs	Automatic RD No	Automatic Force Lbs
1	200	1	185
2	235	2	210
3	220	3	185
4	220	4	190
5	220	5	---
AVG	220		195

Average for both new barrels

Single Shot - 230; Automatic 185 lbs

Average for both used barrels

Single Shot 372; Automatic 330 lbs

For Official Use Only

TABLE II

SUMMARY OF CARTRIDGE EXTRACTION FORCES - M16A1 RIFLE
FIRING TESTS WITH EXTRACTOR NO. 2

FIRING MODE - AUTOMATIC - USED BARREL, S.N. 17288

Test No.	Extraction Force Lbs.									
	RD.1	RD.2	RD.3	RD.4	RD.5	RD.6	RD.7	RD.8	RD.9	RD.10
1	490	490	420	490	410	------------------Not Taken------------------				
2	420	450	455	400	360	390	400	360	430	430
3	424	375	420	360	410	410	380	410	360	330

FIRING MODE - SINGLE SHOT - SAME BARREL

Test No.	Load - Lbs				Remarks
	RD.1	RD.2	RD.3	RD.4	Rds 1 and 4 Failed to Extract
4	560	550	550	485	

FIRING MODE - AUTOMATIC - NEW BARREL, S.M. 19081

Test No.	Extraction Force Lbs.									
	RD.1	RD.2	RD.3	RD.4	RD.5	RD.6	RD.7	RD.8	RD.9	RD.10
5	200	180	190	180	160	180	160	200	--Not Taken--	
6	180	170	190	190	Not Taken					

FIRING MODE - SINGLE SHOT - SAME BARREL

Test No.	Extraction Force Lbs.	
	RD.1	RD.2
7	170	210

TABLE III

SUMMARY OF EXTRACTOR MOMENTUMS - M16A1 RIFLE
FIRING TESTS WITH EXTRACTION NO. 3

NEW BARREL S.N. 19092		NEW BARREL S.N. 19081		PITTED CHAMBER S.N. 17233		PITTED CHAMBER S.N. 17288	
Rd. No.	Momentum gm sec.	Rd. No.	Momentum gm sec.	Rd. No.	Momentum gm sec.	Rd. No.	Momentum gm sec.
1	4.54	1	7.04	1	6.24	1	8.51
2	4.88	2	5.68	2	7.60	2	8.74
3	4.88	3	5.12	3	7.38	3	8.51
4	4.65	4	5.22	4	6.92	4	8.51
5	4.77	5	5.33	5	7.15	5	8.51
6	5.68	6	4.99	6	6.81	6	8.63
7	4.88	7	5.90	7	5.68	7	7.72
8	5.68	8	5.11	8	6.81	8	8.17
9	4.99	9	5.68	9	6.02	9	7.72
10	4.77	10	6.02	10	8.51	10	7.94
11	5.68			11	8.40	11	7.94
Max.	5.68		7.04		8.51		8.74
AVG.	5.04		5.61		7.05		8.28
Min.	4.54		4.99		5.68		7.72

Avg. of both new barrels = 5.31 gm. sec.

Avg. of both used barrels = 7.67 gm. sec.

TABLE IV

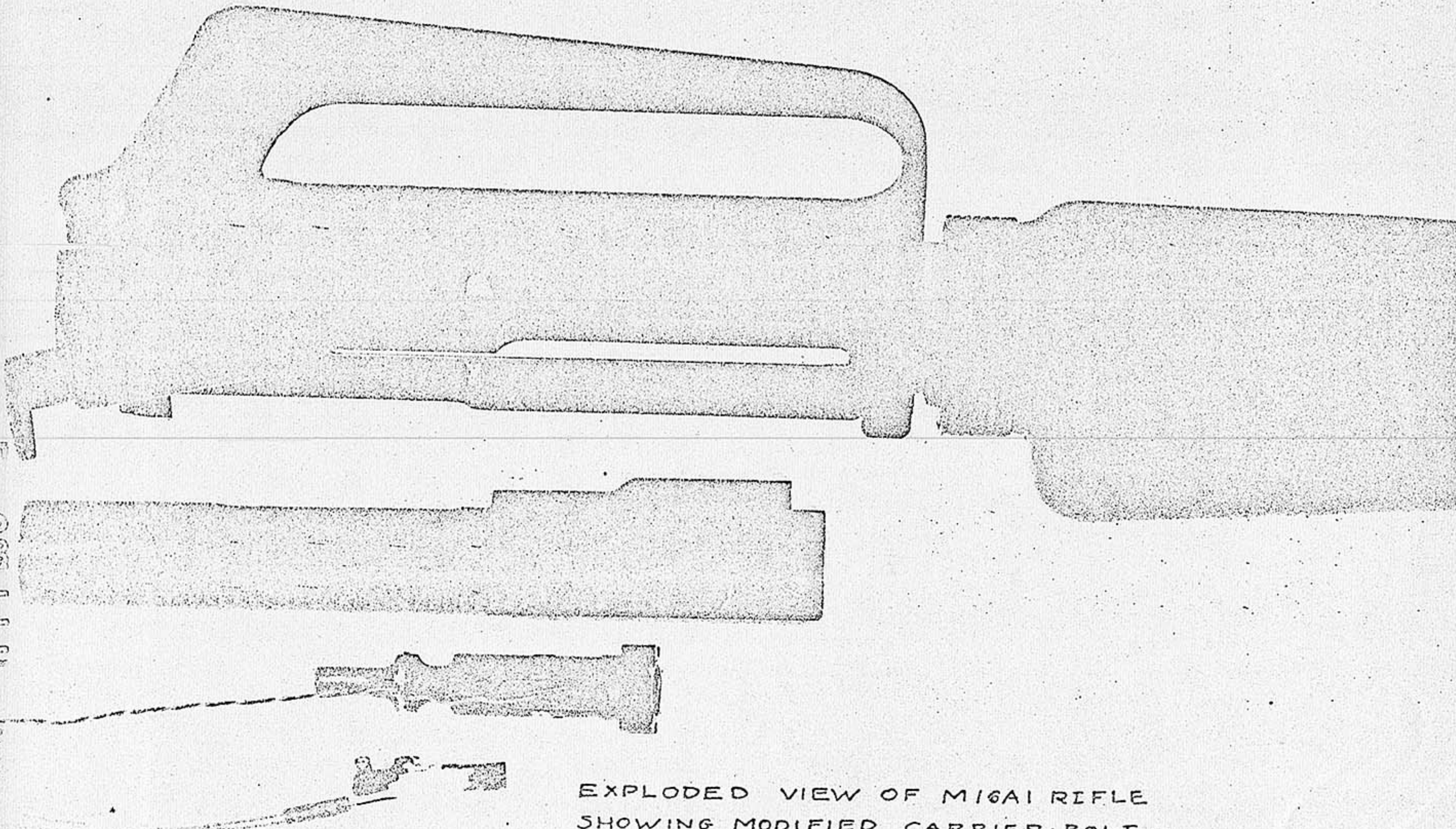
SUMMARY OF STATIC EXTRACTION FORCES - M16A1 RIFLE
AFTER FIRING

New Barrel
S.N. 190932

Rd. No.	Extraction Force
1	2 oz
2	2 "
3	5 "
4	3 "
5	1 lb
6	4 oz
7	10 "
8	12 "
9	1 lb 5 oz
10	1 lb
Avg.	9.1 oz

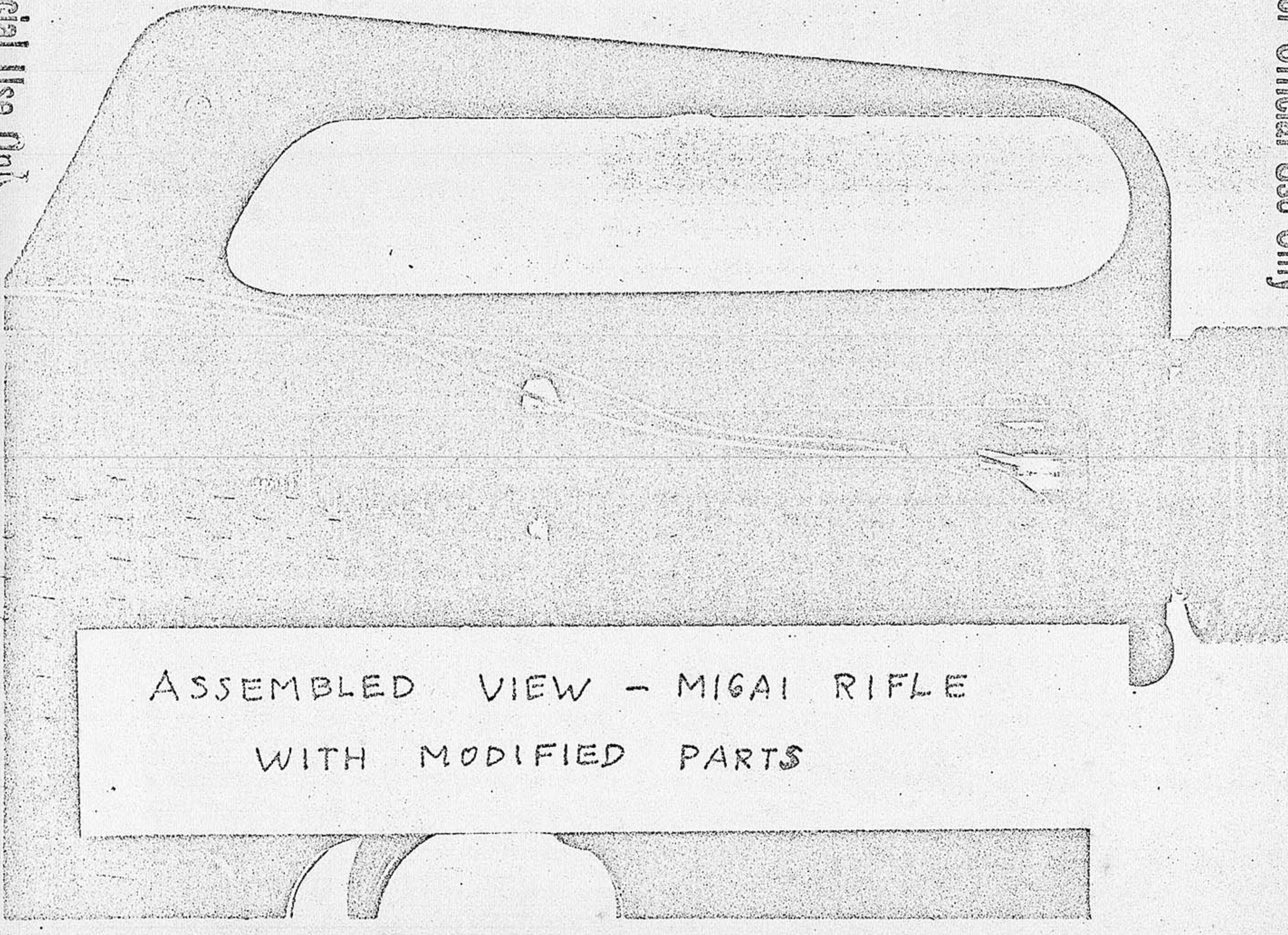
Used Barrel
S.N. 17233

Rd. No.	Extraction Force
1	2 oz.
2	4 "
3	2 "
4	1 "
5	1 "
6	3 lb 4 oz
7	1 oz
8	1 "
9	1 "
10	1 "
Avg.	6.6 oz.



EXPLODED VIEW OF M16A1 RIFLE
SHOWING MODIFIED CARRIER·BOLT,
RECEIVER·UPPER, AND EXTRACTOR
WITH STRAIN GAGE

For Official Use Only



ASSEMBLED VIEW - M16A1 RIFLE
WITH MODIFIED PARTS

For Official Use Only

Object

Considerable force is required to extract the cartridge case from the chamber of the M-16 Rifle. The object of this study is to obtain the radial force, between the cartridge case and the chamber, when the case is being extracted. Extraction force is the coefficient of friction times the radial force.

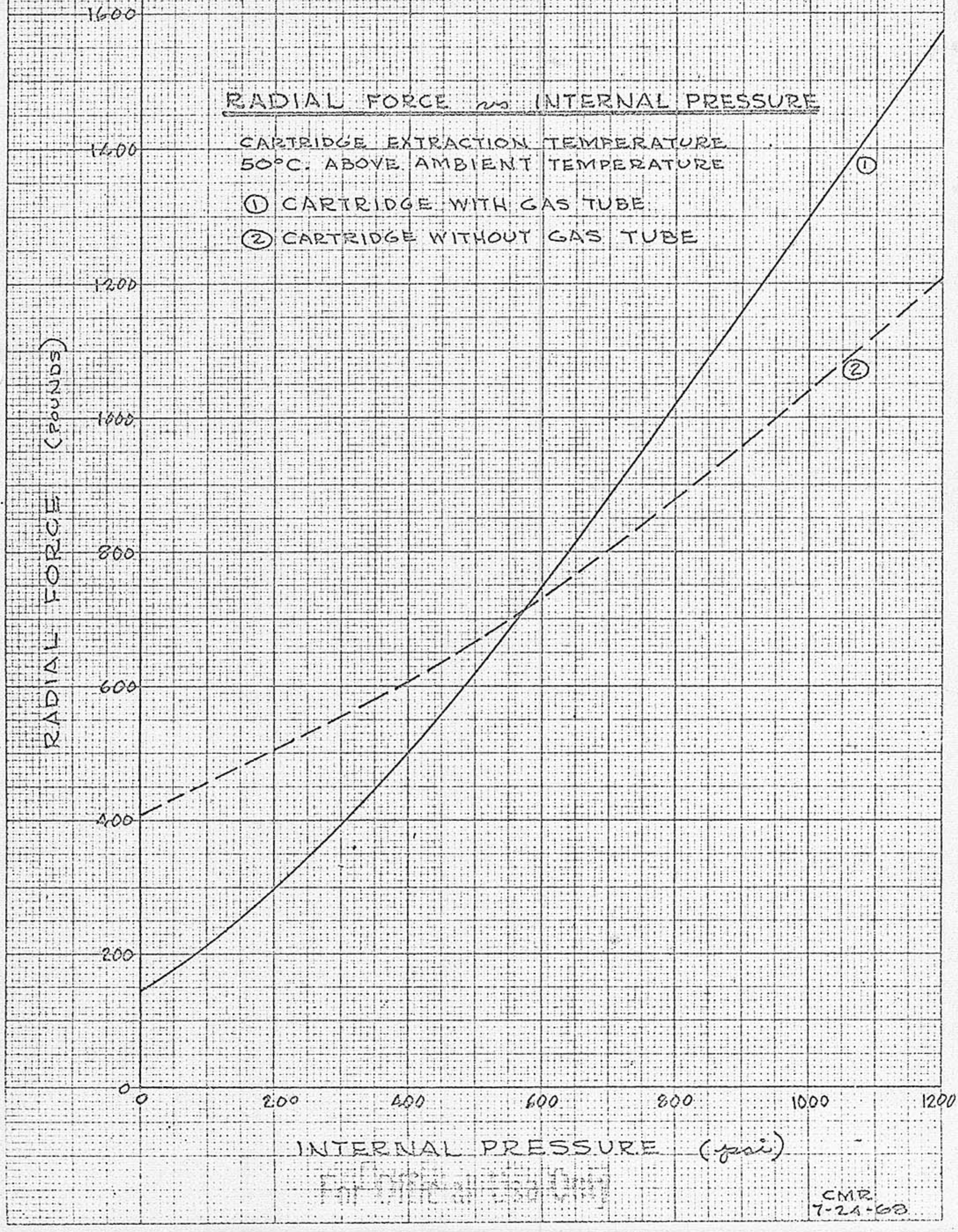
Results

This study shows that there is a substantial increase in the radial force when the pressure in the cartridge case is increased. A graph of the radial force versus the cartridge internal pressure is shown on the following page.

Results could be significantly changed if more tests were averaged. Only 3 cartridges were fired with the gas tube and 3 without the gas tube. On some measurements the round to round variation was greater than the difference between the measurements with and without the gas tube. Not only the dimensional differences, but those due to pressure variations should also be considered.

Recommendations

It is recommended that more rounds be fired, both with and without the gas tube, to minimize the effect of ammunition variation in further calculations. A more thorough investigation should be made, taking into consideration all the existing variables.


RADIAL FORCE vs INTERNAL PRESSURE
CARTRIDGE EXTRACTION TEMPERATURE
50°C. ABOVE AMBIENT TEMPERATURE
① CARTRIDGE WITH GAS TUBE
② CARTRIDGE WITHOUT GAS TUBE
RADIAL FORCE (POUNDS)
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
INTERNAL PRESSURE (psi)
CMR
7-24-68

Procedure

Some pressure remains in the cartridge case when the case is being extracted. This pressure increases the force between the cartridge case and chamber.

The cartridge case diameters were measured before and after firing. The chamber diameter was also measured at locations corresponding to the locations of the case measurement. Measured data, from Frankford Arsenal, is shown in table I.

The case was measured at ambient temperature, therefore the dimensions were adjusted to compensate for the temperature of the case being hotter at the time of extraction. This temperature difference is estimated to be 50° centigrade.

The pressure required to reduce to zero the clearance between the cartridge case and the chamber was calculated. This pressure was then subtracted form the internal pressure. The resulting pressure was then integrated, over the surface area of the cartridge case, to determine the radial pressure.

Assumptions

1. It should be noted that this study is based on measured data from a total of 6 cartridges fired: 3 with the gas tube and 3 without the gas tube. The three tests of each type are averaged and the forces calculated from this averaged data. Results could be significantly changed if more tests were averaged.

2. The thin wall, open end, theory of tube expansion is used.

Symbols:

F = radial force

p = pressure required to bring clearance to 0

p_i = internal pressure in cartridge case

X = distance along case from reference surface

L = " " " " end of case

t = thickness of case

D_o = outside diameter of case

D = mean diameter of the case

D_i = inner diameter of the case

R = mean radius of the case

Δ = clearance between case and chamber (measured on the diameter)

$L = x + .13''$

E = modules of elasticity = 15.9×10^6

Analysis

Temperature expansion:

The coefficient of thermal expansion of the brass case is 20.16×10^{-6} inches per inch per degree centigrade.

$$20.16 \times 10^{-6} \times 50 = .001008$$

Measurements, at plus 50°C, would be 1.001008 times the measurements at ambient temperature.

Pressure formula:

Radial displacement equals R (Hoop stress) / E

$$\frac{\Delta}{2} = \frac{R}{E} \; \frac{p\,D_i}{2t}$$

$$\frac{\Delta}{2} = \frac{D}{2E} \; \frac{p\,D_i}{2t}$$

$$\Delta = \frac{D\,p\,D_i}{2t\,E}$$

$$p = \frac{2t\,E\,\Delta}{D\,(D_i)}$$

$$p = \frac{2t\,E}{(D_o-t)\,(D_o-2t)}$$

Neglecting the t^2 term:

$$p = \frac{2t\,E\,\Delta}{D_o^2-3t\,D_o} = \frac{2t\,E\,\Delta}{D_o(D_o-3t)}$$

Radial Force

$$F = \int_{L=.2}^{L=1.438} (p_i-p)\,\pi\,D_o\,dL + \int_{L=1.5624}^{L=1.76} (p_i-p)\,\pi\,D_o\,dL$$

where only positive values of $(p_i - p)$ are used.

TABLE I

CHAMBER AND CARTRIDGE DIAMETERS

Chamber Location	Chamber Diameter	Cartridge WGT Before	Cartridge WGT After	Cartridge WGT Diff	Cartridge WOGT Before	Cartridge WOGT After	Cartridge WOGT Diff	Difference WGT - WOGT
1	2	3	4	5	6	7	8	9
.250	.3760	.3700	.3757	.0003	.3700	3752	.0008	.0005
		.3701	.3757	.0003	.3700	.3751	.0009	.0006
		.3700	.3755	.0005	.3700	.3752	.0008	.0003
.500	.3710	.3658	.3704	.0006	.3668	.3702	.0008	.0002
		.3665	.3706	.0004	.3669	.3700	.0010	.0006
		.3658	.3704	.0006	.3662	.3704	.0006	.0000
.750	.3665	.3618	.3660	.0005	.3635	.3661	.0004	-.0001
		.3625	.3661	.0004	.3626	.3656	.0009	.0005
		.3618	.3660	.0005	.3620	.3657	.0008	.0003
1.00	.3622	.3564	.3618	.0004	.3578	.3618	.0004	.0000
		.3574	.3621	.0001	.3566	.3625	-.0003	-.0004
		.3570	.3618	.0004	.3564	.3618	.0004	.0000
1.250	.3578	.3512	.3576	.0002	.3512	.3577	.0001	-.0001
		.3517	.3575	.0003	.3513	.3587	-.0009	-.0012
		.3515	.3580	-.0002	.3515	.3581	-.0003	-.0001
1.375	.2943	.2970	.2980	-.0037	.2973	.2973	-.0030	.0007
		.2967	.2970	-.0027	.2972	.2975	-.0032	-.0005
1.500	.2564	.2483	.2550	.0014	.2484	.2558	.0006	-.0008
		.2484	.2570	-.0006	.2486	.2567	-.0003	.0003
		.2483	.2552	.0012	.2482	.2557	.0007	-.0005

Notes: WGT = with gas tube
WOGT = without gas tube
Col 5 = Column 2 - Column 4
Col 8 = Column 2 - Column 7
Col 9 = Column 8 - Column 5

CHAMBER LOCATION	CHAMBER DIAMETER	CARTRIDGE W.G.T. AVERAGE MEASURED DIAMETER AFTER FIRING	CARTRIDGE W.O.G.T. AVERAGE MEASURED DIAMETER AFTER FIRING.
.250	.3760	.37563	.37517
.500	.3710	.37047	.37020
.750	.3665	.36603	.36580
1.000	.3622	.36190	.36203
1.250	.3578	.35770	.35817
1.500	.2564	.25573	.25607

CARTRIDGE TEMPERATURE INCREASED 50° C

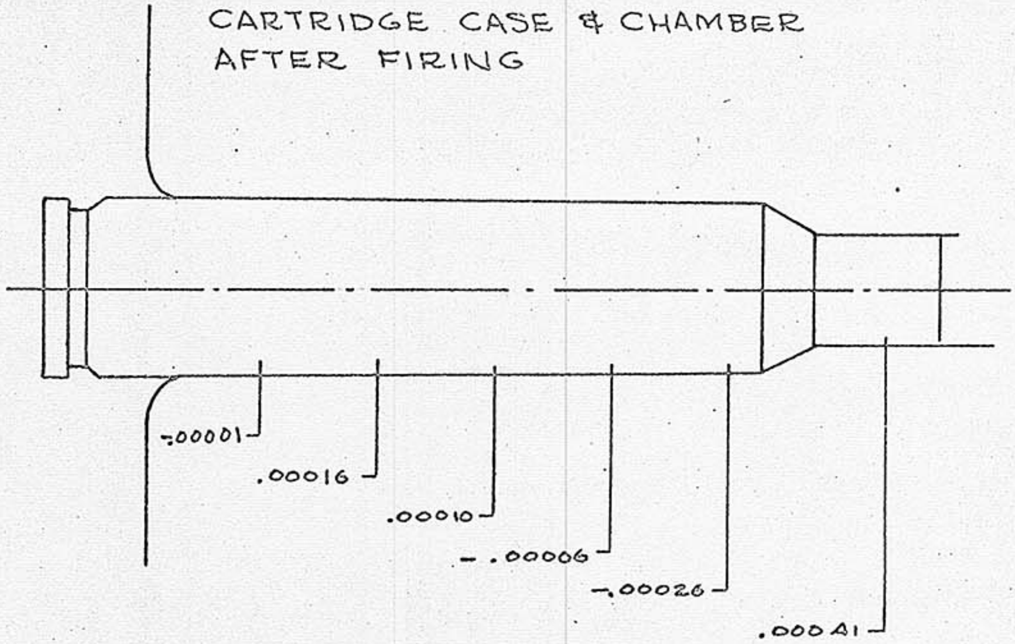
CARTRIDGE WITH GAS TUBE

CHAMBER LOCATION	DIA	AV. AFTER DIA	DIFF (Δ)	t	p
.250	.3760	.37601	−.00001	.0271	−78.
.500	.3710	.37084	.00016	.01447	606.
.750	.3665	.36640	.00010	.01048	272.
1.000	.3622	.36226	−.00006	.00856	−134.
1.250	.3578	.35806	−.00026	.0075	−516.
1.500	.2564	.25599	.00041	.0125	2914.

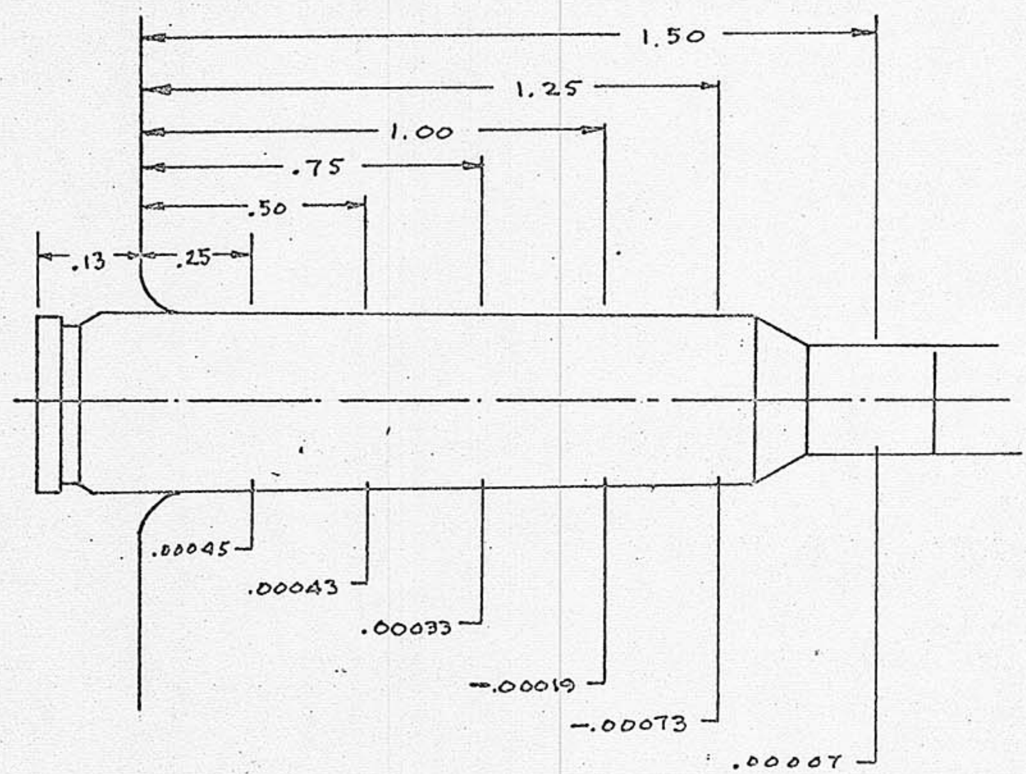
CARTRIDGE WITHOUT GAS TUBE

CHAMBER LOCATION	DIA	AV. AFTER DIA.	DIFF (Δ)	t	p
.250	.3760	.37555	.00045	.0271	3509
.500	.3710	.37057	.00043	.01447	1632
.750	.3665	.36617	.00033	.01048	897
1.000	.3622	.36239	−.00019	.00856	−424.
1.250	.3578	.35853	−.00073	.0075	−1445.
1.500	.2564	.25633	.00007	.0125	496.

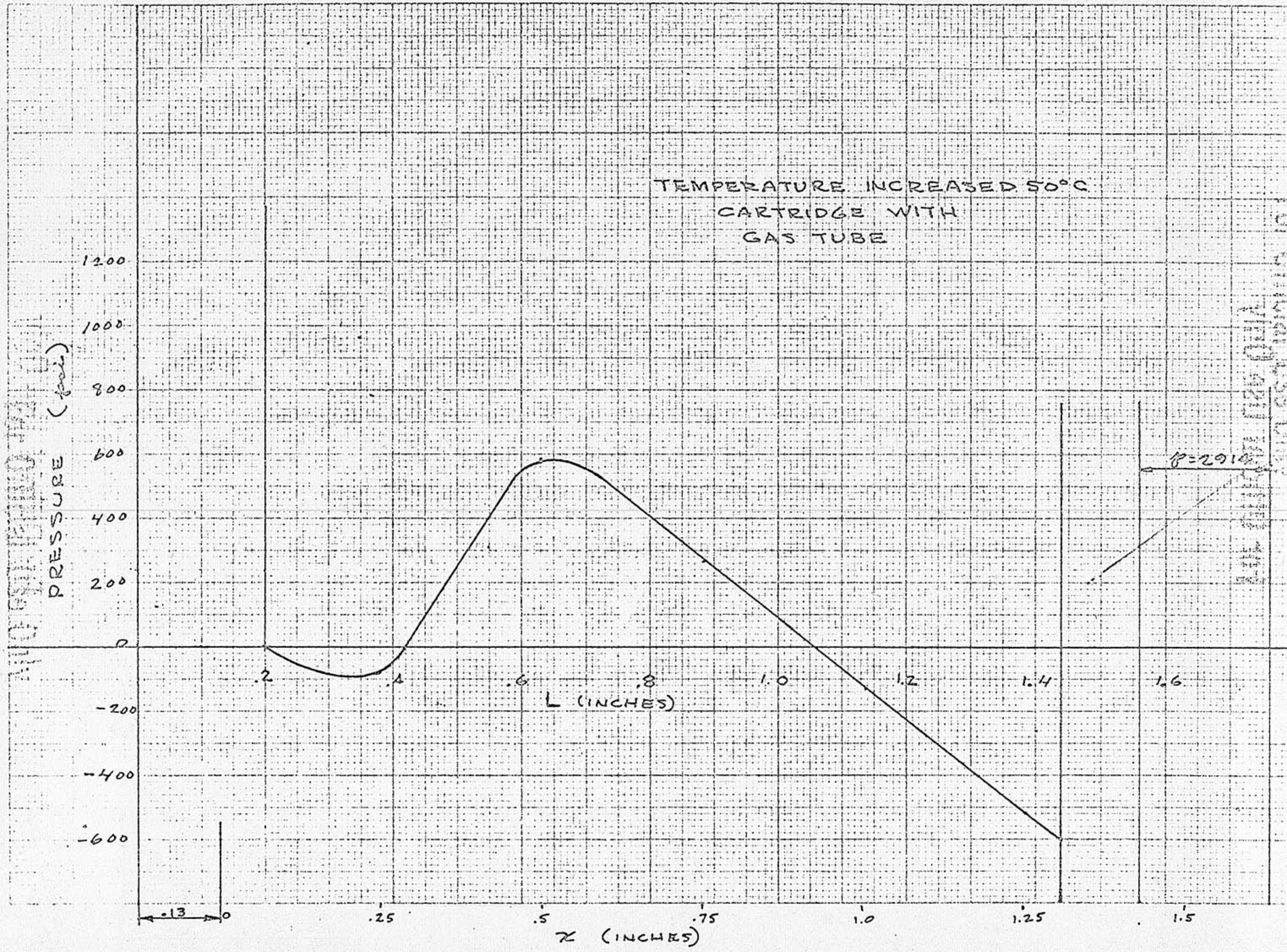
DIAMETRICAL CLEARANCE BETWEEN CARTRIDGE CASE & CHAMBER AFTER FIRING

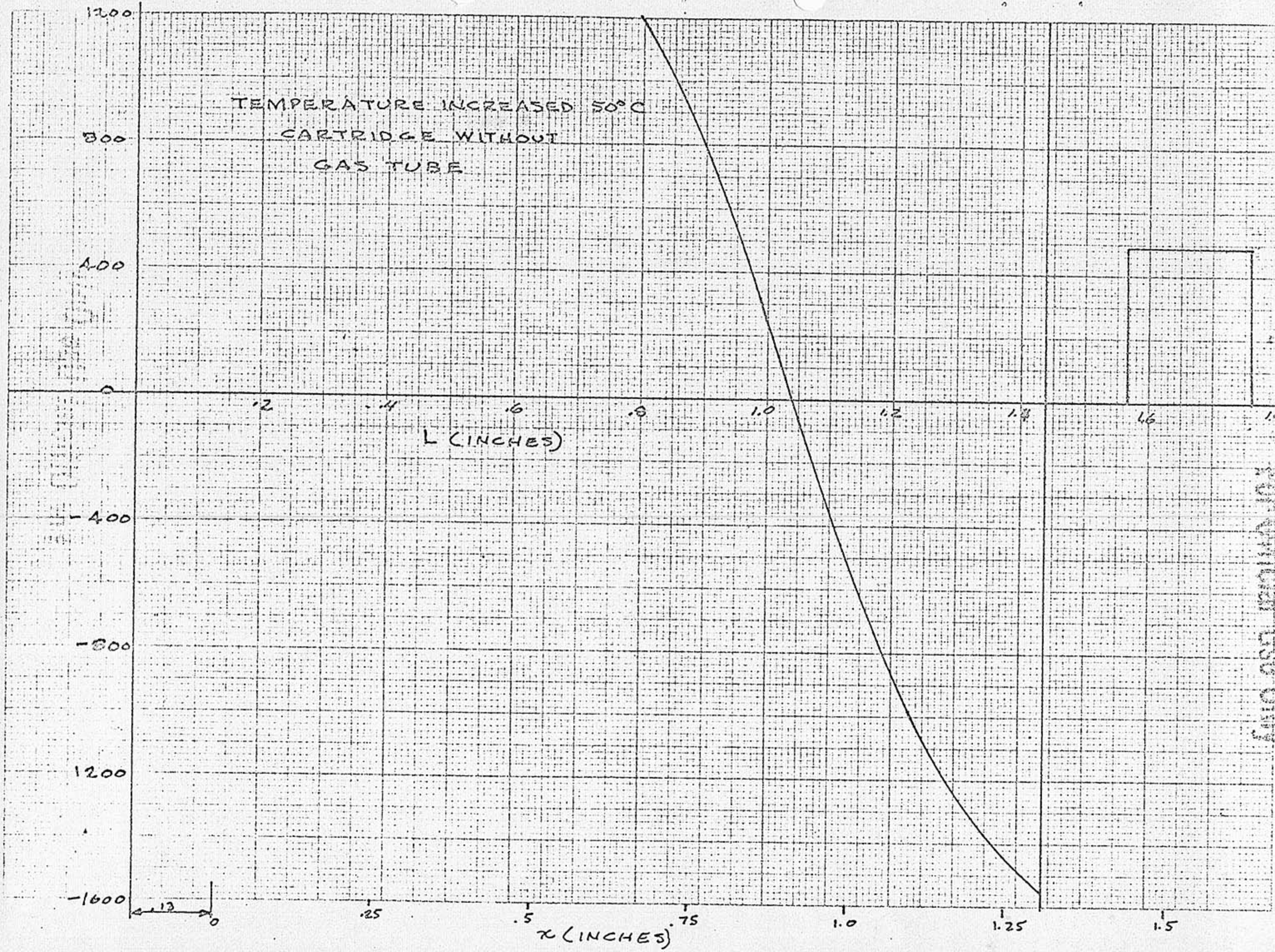


CARTRIDGE WITH GAS TUBE



CARTRIDGE WITHOUT GAS TUBE


TEMPERATURE INCREASED 50°C
CARTRIDGE WITH
GAS TUBE
PRESSURE
1200
1000
800
600
400
200
0
-200
-400
-600
.2
.4
.6
.8
1.0
1.2
1.4
1.6
L (INCHES)
.13
0
.25
.5
.75
1.0
1.25
1.5
x (INCHES)



TEMPERATURE INCREASED 50°C
CARTRIDGE WITHOUT
GAS TUBE
1200
800
400
0
-400
-800
1200
-1600
.2
.4
.6
.8
1.0
1.2
1.4
1.6
L (INCHES)
.13
0
.25
.5
.75
1.0
1.25
1.5
x (INCHES)

TEMPERATURE INCREASED 50°C
CARTRIDGE WITH GAS TUBE

$p = 0 \quad F = \left[\frac{1}{2}(.38)(600) + 60(.2)\right]\pi(.36) = 142$

$p = 200 \quad F = F_0 + \left[\frac{.51+.38}{2} + \frac{.27+.21}{2}\right]200\,\pi(.36) = 297$

$p = 400 \quad F = F_{200} + \left[\frac{.64+.51}{2} + \frac{.34+.27}{2}\right]200\,\pi(.36) = 496$

$p = 600 \quad F = F_{400} + \left[\frac{.77+.64}{2} + \frac{.41+.34}{2}\right]200\,\pi(.36) = 741$

$p = 800 \quad F = F_{600} + .124(200)\,\pi(.36) = 1021$

$p = 1000 \quad F = F_{800} +$ " $= 1302$

$p = 1200 \quad F = F_{1000} +$ " $= 1582$

TEMP INC. 50°C
CARTRIDGE w/o GAS TUBE

$p = 0 \quad F = \frac{1}{2}(.4)(1800)\,\pi(.36) = 407.$

$p = 200 \quad F = F_0 + .42(200)\,\pi(.36) = 502.$

$p = 400 \quad F = F_{200} + .46(200)\,\pi(.36) = 606.$

$p = 600 \quad F = F_{400} + .48(200)\,\pi(.36) + 104(.1976)\,\pi(.255) = 731.$

$p = 800 \quad F = F_{600} + .52(200)\,\pi(.36) + 200(.1976)\,\pi(.255) = 880.$

$p = 1000 \quad F = F_{800} + .57(200)\,\pi(.36) + 200(.1976)\,\pi(.255) = 1041.$

$p = 1200 \quad F = F_{1000} + .62(200)\,\pi(.36) + 200(.1976)\,\pi(.255) = 1213..$

FRANKFORD ARSENAL REPORT 7/30/68

Samples of WC 846 and IMR 8208M Propellants

Peak Pressures in psi - WC 846 / IMR 8208M

Temp	WC 846 Port	WC 846 Chamber	IMR 8208M Port	IMR 8208M Chamber
-40°F	12,900	46,000	11,000	51,000
+70°F	13,000	54,700	12,000	50,100
+155°F	12,500	63,000	11,800	48,100

Times to Peak Pressure and Bullet Exit in Milliseconds

Temp	WC 846 PP	WC 846 BE	IMR 8708M PP	IMR 8708M BE
-40°F	.70	1.23	.45	1.05
+70°F	.77	1.30	.50	1.08
+155°F	.71	1.19	.44	.96

Bullet Velocity in Ft/Sec.

	WC 846	IMR 8208M
-40°F	2934	------
+70°F	3200	3072
+155°F.	----	3242

U S ARMY FRANKFORD ARSENAL
BASIC MATERIALS EVALUATION LABORATORY (Q6100)
QUALITY ASSURANCE DIRECTORATE

RESIDUE DATA

LABORATORY REPORT

NO. 155814 DATE 19 April 1968

MATERIAL Fouling - Addendum #3

REPRESENTING Six (6) Weapons - M16 LOT NO. P. O.

FROM TO Mr. J. Daily, Q3000-235-3

SPECIFICATION & DATE X.O. 86206-92

CHEMICAL AND SPECTROGRAPHIC ANALYSIS

Barrels #	864697-TB-0	861480-TB-CL	860461-TI-0	846891-TI-CL
Total residue (in mg.)	868.6	212.5	750.1	485.3
Methylene Dichloride				
(a) Soluble	334.5	107.6	269.5	169.5
(b) Insoluble	534.1	104.9	480.6	315.8
Total residue (chemical analysis - reported in mg).				
(a) Copper	131.2	22.6	152.9	73.8
(b) Barium	54.7	7.8	33.9	13.6
(c) Lead	9.7	0.1	4.8	1.1
Remainder of residue (spectrographic estimation in percent).				
(a) Iron	1/3	3/7	2/4	4/8
(b) Potassium	.2/.5	.2/.5	5/15	3/7
(c) Aluminum	2/4	2/4	2/4	1/3
(d) Molybdenum	.2/.5	.2/.5	4/8	4/8
(e) Zinc	4/8	4/8	4/8	4/8
(f) Phosphorus	4/8	.8/1.5	4/8	4/8
(g) Antimony	4/8	1/2	.1/.3	.2/.5
(h) Sodium	.1/.3	.3/.7	.3/.7	.2/.5
(i) Calcium	5/9	3/6	.4/.8	.4/.8
(j) Lithium	.05/.15	.1/.3	.01/.1	.01/.1
(k) Magnesium	.4/.8	.2/.5	.1/.3	1/2
(l) Manganese	.3/.7	.8/1.5	.1/.3	.3/.7

Legend: 1/3 represents range of 1% to 3%.

\# all barrels substantially rusted on outer surface.

(See Sheet #2)

U S ARMY FRANKFORD ARSENAL
BASIC MATERIALS EVALUATION LABORATORY (Q6100)
QUALITY ASSURANCE DIRECTORATE

LABORATORY REPORT

NO. 155814 (Sheet #2) DATE

MATERIAL

REPRESENTING LOT NO. P. O.

FROM TO

SPECIFICATION & DATE X.O.

Receiver group	864697 TB-Ø	861908 TB-L	861488 TB-CL	860461 TI-Ø	855566 TI-L	846851 TI-CL
Total residue (in mg.)	7977.9	5660.5	3174.2	4131.9	4004.4	2414.6
Methylene Dichloride						
(a) Soluble	3316.6	2952.5	1694.1	2361.5	2852.5	1678.4
(b) Insoluble	4661.3	2708.0	1480.1	1770.4	1151.9	736.2
Total residue (chemical analysis-reported in mg).						
(a) Copper	1549.8	1047.8	638.4	965.3	968.4	236.2
(b) Barium	298.5	95.4	45.9	66.9	48.7	18.1
(c) Lead	Lost	3.8	4.3	19.7	11.1	8.9
Remainder of residue (spectrographic estimation in percent).						
(a) Iron	1/3	1/3	1/3	2/4	2/4	1/3
(b) Potassium	.2/.5	.2/.5	.3/.6	5/15	4/8	3/7
(c) Aluminum	2/4	2/4	3/6	3/6	.7/1.3	1/3
(d) Molybdenum	2/4	2/4	10/20	10/20	10/20	4/8
(e) Zinc	5/15	5/15	5/15	4/8	4/8	4/8
(f) Phosphorus	.5/.9	1/2	.3/.7	.3/.7	.7/1.2	.4/.8
(g) Antimony	.1/.3	.1/.3	<.1	.2/.5	.2/.5	.2/.5
(h) Sodium	.2/.5	.2/.5	.5/.9	.2/.5	.1/.3	.2/.5
(i) Calcium	5/15	5/15	10/30	.3/.7	.3/.7	.4/.8
(j) Lithium	.01/.1	.03/.3	.01/.1	.01/.1	.01/.1	.01/.1
(k) Magnesium	.5/1.5	1/2	1/2	.5/1.5	.3/.7	1/2
(l) Manganese	.1/.3	.1/.3	.1/.3	<.1	<.1	.3/.7

Gas tubes: Samples reserved for study to be reported in addendum #6.
Remarks: The bolts of each series (i.e., TB and TI) contained a residue which adhered tenaciously to the area.

< = Less than

For Information Only!

GEORGE HORWITZ
Chemist

Report Approved:

SAMUEL SITLMAN
Chief, Basic Materials Evaluation Laboratory

SMUFA-Q Form 10, Rev 1 Mar 67 (Supersedes ...)

D

For Official Use Only

DEPARTMENT OF THE ARMY
U. S. ARMY BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND 21005

AMXBR-IA

10 June 1968

SUBJECT: Gas Tube Clogging, M16 Rifle

Commanding Officer
Frankford Arsenal
ATTN: Dr. H. P. Manning, Deputy Director
Ammunition Development & Eng Labs
Philadelphia, Pennsylvania 19137

1. Some recent work in the Interior Ballistics Laboratory of the Ballistic Research Laboratories by Mr. Geene, might be of interest as an aid in developing a technique for identifying or screening "clean" or "dirty" lots of propellants for the M16 rifle. The technique developed was primarily for collecting and identifying the material that came through the gas tube and deposited in the bolt carrier of the M16 rifle. The apparatus developed is a small cyclone separator which is attached to the end of a modified gas tube and serves as a collector for the solid material flowing through the gas tube. A photograph of the M16 rifle with the collector is attached as inclosure one.

2. Four different lots of 5.56mm ammunition were fired in the M16 rifle with the collector attached. The four lots were:

a.	Lot TW 18224	WC-846 w/M-193
b.	Lot LC 12114	WC-846 w/M-196
c.	Lot TW 18205	IMR-8208 w/M-193
d.	Lot LC 12110	IMR-8208 w/M-196

Each lot was fired in two - 200 round series. The material collected in the collector was weighed after each 200 round series. The collected material was then separated into organic and inorganic portions by extraction with benzene, methanol, and acetone. An infrared spectra of the organic material indicated the presence of nitrocellulose, i.e., partially consumed propellant. Currently an emission spectra is being run on the inorganic material for identification and for the relative amounts of the major ingredients in the collected inorganic material.

AMXBR-IA
SUBJECT: Gas Tube Clogging, M16 Rifle

10 June 1968

3. The amount of material collected for each 200 round series for each of the ammunition lots indicates that the collector may also serve as a technique for screening "clean" and "dirty" propellants. The amount of material collected for 200 rounds is as follows:

Lot TW 18224	200 Rounds	0.443 grams
Lot TW 18224	200 Rounds	0.439 grams
Lot LC 12114	200 Rounds	0.671 grams
Lot LC 12114	200 Rounds	0.697 grams
Lot TW 18205	200 Rounds	0.301 grams
Lot TW 18205	200 Rounds	0.285 grams
Lot LC 12110	200 Rounds	0.407 grams
Lot LC 12110	200 Rounds	0.447 grams

4. The first two lots (TW 18224 and LC 12114) are loaded with WC-846 propellant, the first lot with ball M-193 and the second lot with tracer M-196. The agreement in the amount of material collected in each 200 round series is quite good. The difference in the amount collected between the first two lots may be due to differences in propellant lots and not necessarily due to the fact that one lot was loaded with ball M-193 and the other with tracer M-196.

5. The second two lots (TW 18205 and LC 12110) are loaded with IMR-8208 propellant, the first lot with ball M-193 and the second lot with tracer M-196. The agreement in the amount of material collected in each 200 round series is again quite good. There is a difference in the amount of material collected when comparing the two lots, the tracer lot giving the larger amount of material.

6. The amount of material collected for the ammunition lots loaded with WC-846 propellant is greater than for the ammunition lots loaded with IMR-8208 propellant. The ratio of amount of organic to inorganic material is also different as shown in the following:

		Organic/Inorganic
Lot TW 18224	200 Rounds	24/76
Lot TW 18224	200 Rounds	24/76
Lot LC 12114	200 Rounds	14/86
Lot LC 12114	200 Rounds	17/83
Lot TW 18205	200 Rounds	48/52
Lot TW 18205	200 Rounds	44/56

AMXBR-IA
SUBJECT: Gas Tube Clogging, M16 Rifle

10 June 1968

Lot LC 12110	200 Rounds	53/43
Lot LC 12110	200 Rounds	42/58

The lots loaded with WC-846 propellant yield a larger ratio of inorganic material than do the lots loaded with IMR-8208 propellant. An analysis of the inorganic material is now being performed. It appears that a large portion of the inorganic material is carbon.

7. The BRL work does show a difference between lots of the same propellant and also a difference between WC-846 propellant and IMR-8208 propellant. This technique may be of use to you in the screening of "clean" and "dirty" propellants. To explore further into the propellant problem we would like to obtain the Propellant Description Sheets for the propellants used in these four ammunition lots, looking into possible differences in composition, coating, and grain size.

8. To further confirm the technique as a method for screening "clean" and "dirty" propellants we would like to obtain 500 rounds each of the "clean" Lot 5244 and the "dirty" Lot 5330. The two lots will be tested in the same manner as the first four lots including the infrared analysis for organic material and the emission spectra for inorganic material. The Propellant Description Sheets for the propellants used in these two lots are requested.

FOR THE COMMANDER:

1 Incl
as

LELAND A. WATERMEIER
Acting Chief
Interior Ballistics Laboratory

For Official Use Only

MEMORANDUM FOR RECORD

19 July 1968

SUBJECT: Study of Pressure Existing in Empty Cartridge Case at Time of Extraction M16 Rifle

The object of this study was to obtain a preliminary indication that pressure exists in the case at the time of extraction and to obtain an approximate estimate of its value.

The procedure consisted of enlarging in amplitude the blowdown portion of the chamber pressure record by increasing the vertical pressure scale from 10,000 psi per cm to 1,000 psi per cm and changing the horizontal time scale from 0.15 ms/cm to 1.00 ms/cm. The first series of tests using Kistler type gages produced unclear pressure-time records. Two problems appeared. First the pressure record did not return to the zero calibration line and second calibration procedure was not available for low pressure values.

As a result of the lack of understanding of the records produced by the Kistler gage Frankford Arsenal repeated the tests with its own MSP gage (a piezo electric crystal gage). Normally this gage is calibrated in 15,000 psi increments from 15,000 psi to 100,000 psi for small arms use where the 15,000 psi increments are obtained by a 500 pound weight acting in a 1/30 square inch piston. For low pressure calibration for this test a preliminary rough approximation was obtained by dropping the calibration weight in increments to 10 lbs (300 psi). Lower calibration requires a hydraulic device, but time did not permit setting up and using this device. However, down to the 300 psi increment no noticeable change in linearity was noted. The MSP gage has a mechanical frequency of about 1 megacycle and hence can be considered to be capable of good response as high as 1/10 megacycles. Previous explosive shock tests show that this gage revealed rises of 60,000 psi in under 10 microseconds. The particular gage used was an improved model having superior linearity at low pressure levels. A gage similar to the one used is shown in Figure 1.

Figure 2 shows one of the records obtained. Two curves are shown: a normal chamber pressure-time curve for ball propellant loaded cartridges and an expansion of the blowdown portion of the same curve. Calibration data is on the back of the record. This second curve was initiated by projectile muzzle exit which occurs at the extreme left vertical grid line. The zero pressure line for this pressure record is the second line from the bottom of the picture. The scale for this blowdown record is 1,000 psi/cm and 1 ms/cm (Note: The grid is in cms). The scale for the chamber pressure curve is 10,000 psi/cm and .150 ms/cm. Muzzle exit is indicated on the chamber pressure record by a change in intensity occurring a little over 1.20 ms from curve initiation.

For Official Use Only

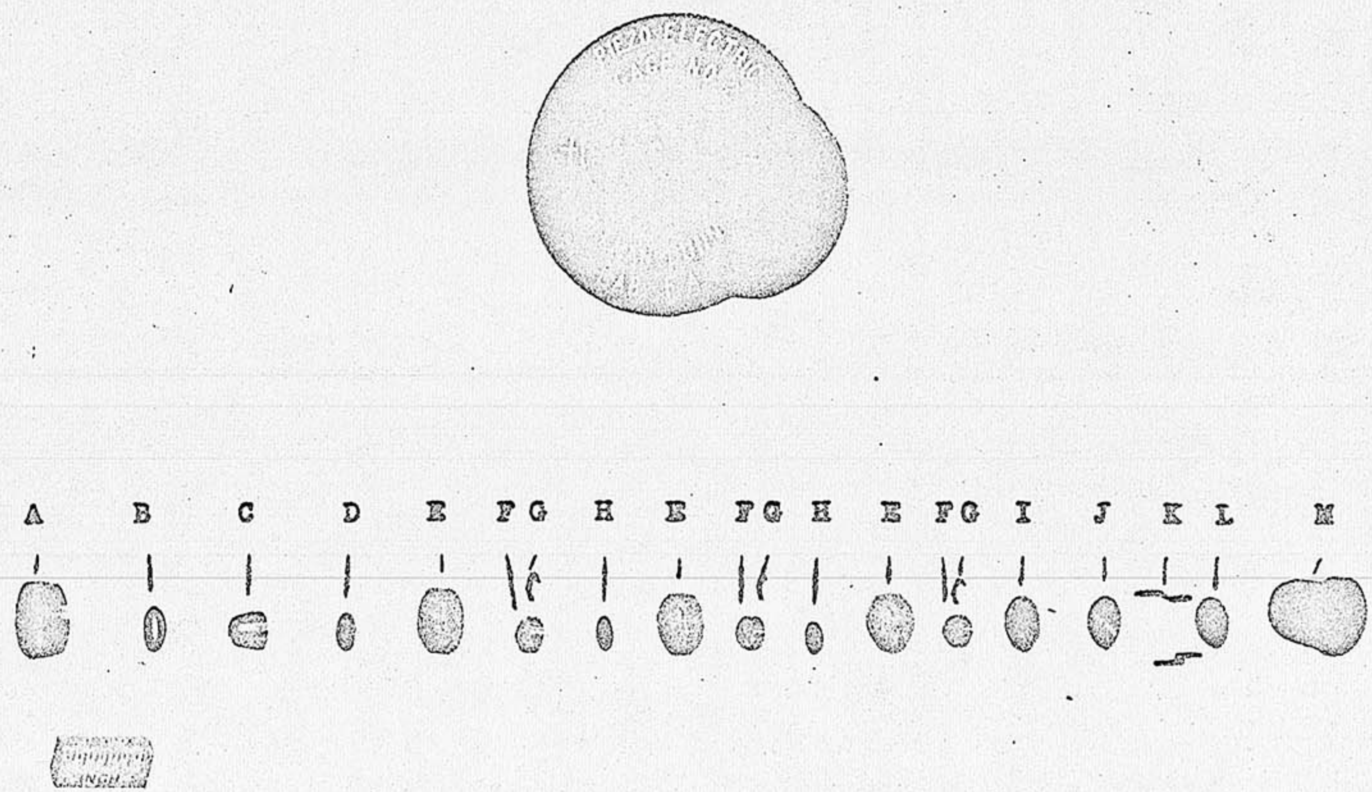
The blowdown curve did not level out on its zero pressure line but fell below it. The chamber pressure curve did not begin on its own zero pressure line but below it. (This is considered to be improper zeroing of the amplifier). It is noted that the values below are about the same (allowing for the 10 to 1 scale difference). Therefore, it appears this is a reliable record except for accurate calibration of the gage at low pressure (below 300 psi).

If a zero calibration line is assumed at the point in which the blowdown curve levels out it is possible to estimate that for this particular firing that pressure did exist in the case at a point in time 3 milliseconds from projectile muzzle exit (point at which extraction occurs) and that its value is approximately 350 psi.

Much more experimentation and refinement of instrumentation is required to verify this first preliminary finding for the population of M16 rifles/ammunition.

C Fawcett

Neg.#20168-19



A - Plug, retaining
B - "O" ring
C - Anvil
D - Wafer, insulation No. 4
E - Insert
F - Plate
G - Clip, spring
H - Quartz, crystal
I - Wafer, insulation No. 3
J - Wafer, insulation No. 2
K - Pin, contact
L - Wafer, insulation No. 1
M - Body, screw

Figure 1 Gage, metal screw piezo

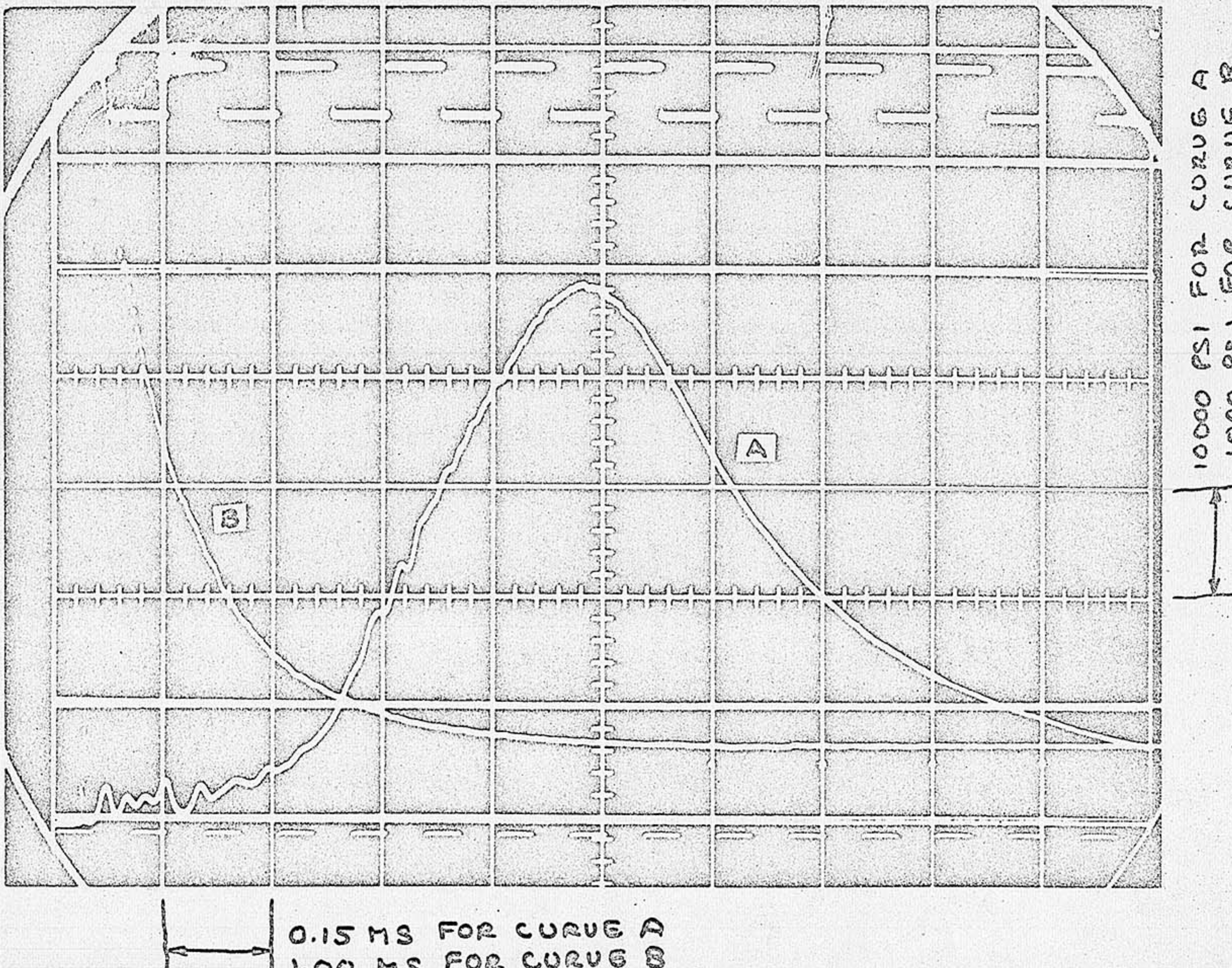
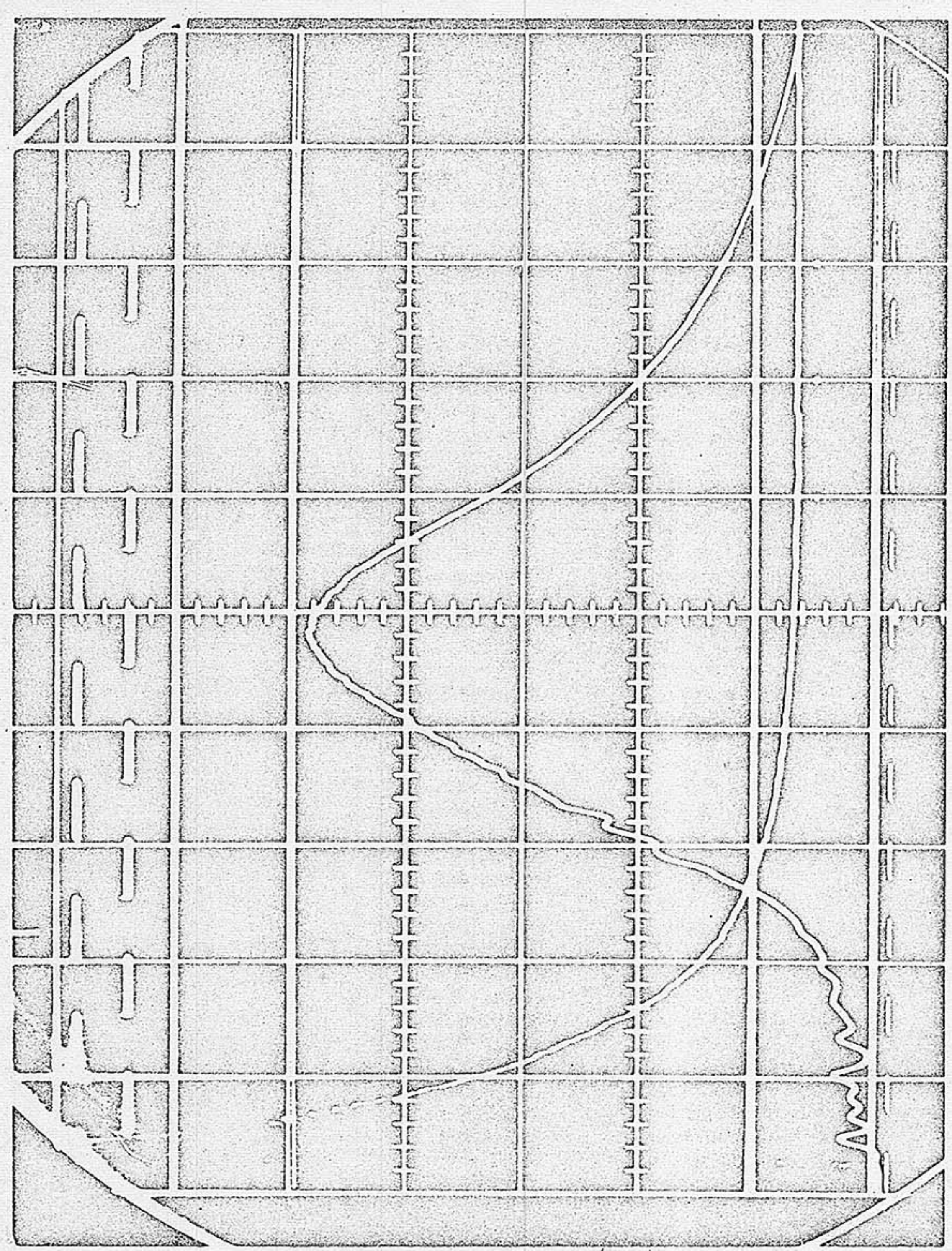
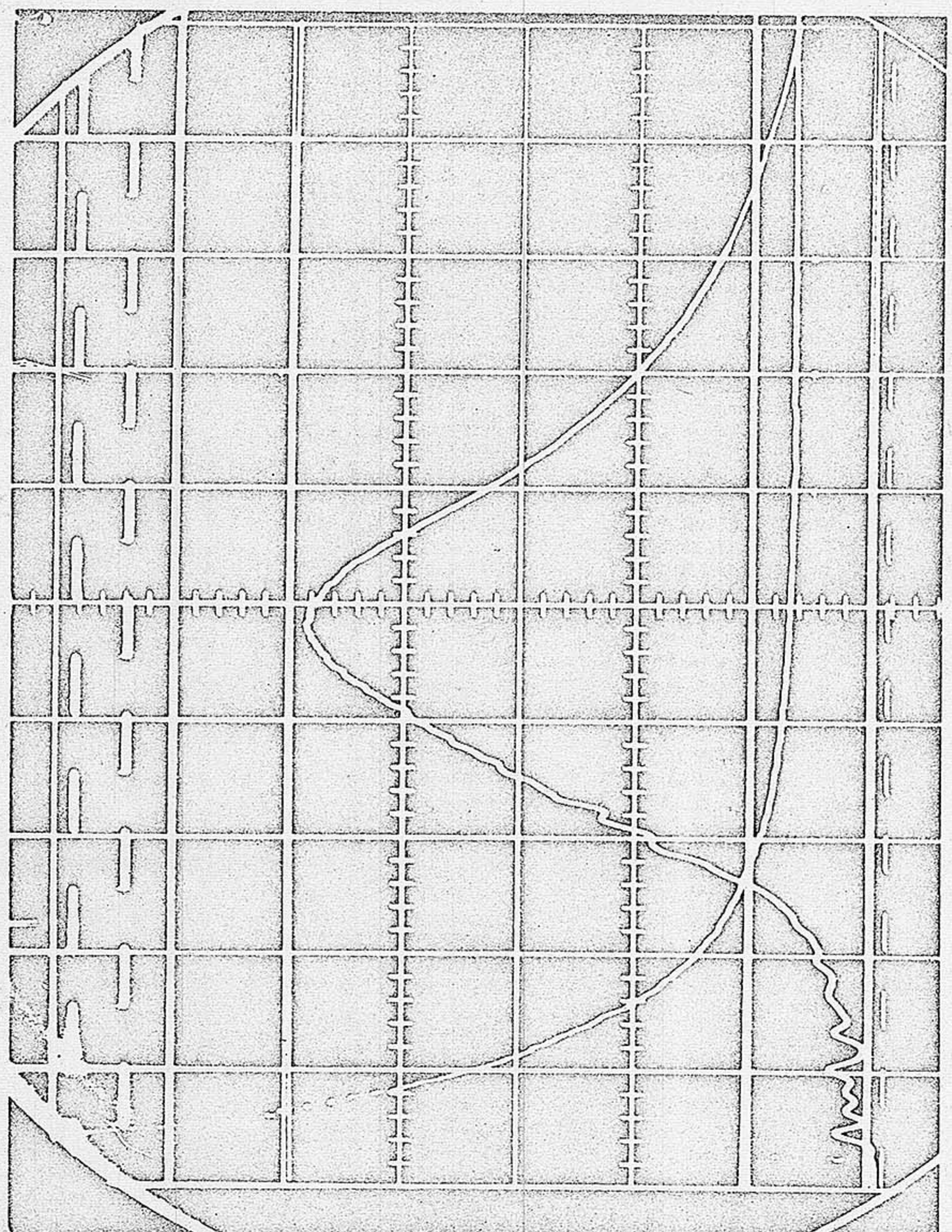

A
B
10000 PSI FOR CURVE A
1000 PSI FOR CURVE B
0.15 MS FOR CURVE A
1.00 MS FOR CURVE B

FIGURE 2



For Official Use Only



SUBJECT: Program Outline of Test and Design Modifications on the M16 Rifle to Reduce Its Malfunction Rate, Dated 8 Aug 68, by Mr. L. R. Ambrosini (Draft Report)

1. Confirming phone conversations of 3 Oct 68, your comments on subject document are required by the Project Manager not later than 10 Oct 68. Copies were distributed to representatives at a meeting of the AMC M16 Steering Group on 15 Aug 68.

2. Your comments should include, specifically, answers to the following questions:

a. Which tasks defined in subject program outline are already adequately covered in your judgment by your programs on the M16/M16A1 subject under cognizance of the AMC M16 Steering Group?

b. Which tasks defined in subject outline are currently in progress at your agency under authority separate from that of the Project Manager and not included in the program coordination records of the AMC M16 Steering Group, and what is your time-phased program for accomplishment of these tasks?

c. Which tasks defined in subject outline and not included in your current programs do you recommend for accomplishment by your agency, and what is your time-phased plan in estimated cost for these proposed tasks?

d. Which task defined in subject outline and not included in your current program do you recommend for accomplishment by agencies other than your own?

e. Which task defined in subject outline do you not recommend for accomplishment, and what are your reasons for not recommending accomplishment of these tasks?

3. You are invited to submit any general comments you consider useful and appropriate in addition to foregoing specific requirements.

4. Considering short time available, your response by teletype is requested to assure availability of information to Project Manager not later than 10 Oct 68.