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FIRING STRAIN MEASUREMENTS ON 76MM GUN M1E2

by

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FIRING STRAIN MEASUREMENTS ON 76MM GUN M1E2

Abstract

Measurements of tangential and axial strain were taken at various points on a 76mm Tube M1E2 while firing the M79 projectile at various pressures from 75 to 115% of normal. Rather high peak strains in both directions were observed at the time the projectile passed, especially near the muzzle. Peak tangential strains on the outer surface due to the rotating band were observed to be around one and one-half times higher than the strain due to the gas pressure, at the thick-walled section; and more than two and a half times higher, near the muzzle.

Introduction

1. According to conventional design practice the factor of safety in gun tubes, based on gas pressure alone, is considerably higher in the chase and at the muzzle than at the breech. Justification for this is found in the fact that expansions and bursts at the muzzle are not uncommon, even with this higher safety factor. In seeking an explanation for such expansions and bursts one hypothesis was presented* to the effect that pressure waves in the gases might induce transverse waves in the steel which under certain conditions would reinforce the usual stresses caused by the gas pressure to produce the observed bursts.

2. Not until comparatively recently however, was the importance of the pressures caused by the rotating band of the shell, realized. In this country, Watertown Arsenal has been studying this matter for sometime**. In connection with recent investigations of the 76mm Gun, the Proving Ground was directed to take the strain measurements reported herein in order to furnish a basis for further studies by Watertown Arsenal.

* R. H. Kent, "A Possible Explanation of Muzzle Bursts and Expansions of Howitzers", Ballistic Research Laboratory Report No. 29, December 16, 1935.

** Also reference is made to the work of the British Gun Design Committee, British Ordnance Board Proceedings, No. 21,628, February 10, 1943, (Conf.)

General

3. In accordance with the program outlined by Watertown Arsenal and approved by the Chief of Ordnance (WA 472.94/11, OO 472.13/1160, APG 472/553-40), strain measurements were taken on the 76mm Tube, M1E2, No. 1111 during firing. Rounds were fired at charges giving 75%, 100%, 105%, 110% and 115% of the normal pressure and records of axial and tangential strain were taken at the gage positions shown on Figure 4.

4. Due to the limitations of the recording equipment available (See Appendix I) only three records could be taken simultaneously. In order to have a continuous reference for coordinating the gage readings at different points, which of necessity were taken on different rounds, one of the recording channels was always connected to the "breech reference gage" (Gage No. 8). This gage recorded the tangential strain on the outer surface of the tube over the chamber, 9-1/2 inches forward of the front edge of the breech ring. Table I is a list of the gages that were used on each round.

Materiel

5. The 76mm Tube M1E2 No. 1111 (Gun, 76mm, M1, No. 1009) was mounted in a special mount consisting of a steel sleigh sliding on a pair of timbers. The sleigh was restrained by a steel cable attached to a recoil mechanism which was anchored to the ground well out in front of the gun. The tube was supported on the sleigh by means of two sets of wooden clamping blocks. The breech end of the gun was butted up against the steel plate which formed the rear end of the sleigh. A hole was cut through this plate to facilitate loading. This mount was located in Stockade 2 at the Main Front.

6. The ammunition used on all rounds was as follows:

a. Projectile, A.P. M79, various lots, Dwg. 78-18-45 (except rounds 30 and 31). On rounds 30 and 31, Shell, HE (inert-loaded) M42B2 was used.

b. Powder, FNH Lot 8007-42 for 3" A.A. Gun Model 1918M. The powder was kept in the constant temperature magazine at 70°F. until time to be fired.

c. Case, 76mm M26, various lots, Dwg. 71-2-123.

d. Primer, 300 grain, M28 A2 KOP Lot 4-6 Dwg. 74-2-63.

7. Other pertinent measurements taken besides the strain gage records included the diameters of the rotating band of each shell, copper pressures using two medium caliber M3 copper pressure gages, solenoid velocities, and the weights of each projectile and propelling charge (Firing Record No. M22215). Mr. Founds was the proof director in charge of the firing.

8. The weight of charge used for each range of pressures was as follows:

75%	50.75 ounces
100%	59.00 "
105%	61.13 "
110%	62.30 "
115%	63.40 "

These charges were established to approximate the above percentages of the average pressure required to give the rated muzzle velocity with this particular powder. Wherever reference is made to a certain "per cent charge" in this report, the above charges are indicated.

Test Procedure

9. The strain gages were mounted and connected to a common terminal board mounted as shown in Figure 2. There were two gage elements for each gage number, connected in series so as to give the total strain in the two elements. The tangential gages were placed 90° apart to eliminate the possible effect of ovality and the axial gages were placed 180° apart to eliminate the effect of bending of the tube. The shielded wires leading to the recording equipment were plugged into the receptacles for the desired gages and the wires laid back with sufficient slack to allow for the recoil movement of the gun.

10. On April 18, ten rounds were fired, five at 75% pressure and five at 100% pressure. Gage No. 8, the breech reference gage, was connected to one of the recording channels during all the firing. In the first days firing it was connected to the lower (No. 3) recording channel and the other two gages were connected to the top and middle channels. The timing signal from a 540 cycle frequency standard was arranged to give a momentary interruption in the record once each 1/540th of a second. This was connected into channel No. 3 so that timing breaks 1.85 milli-seconds apart appeared in the record of the breech reference gage. The muzzle contact circuit was also connected into the same line.

11. Records were taken of simultaneous axial and tangential strain at the same section along the tube on gages 1 and 8, 2 and 9, 4 and 11, and 5 and 12, and of simultaneous axial strain at two different sections along the tube on gages 1 and 3, and 4 and 5. (See Figure 4 for location of gages and plot of representative records.)

12. A brief study of the records obtained in this day's firing indicated a need to repeat some of the rounds. In some cases important peaks were lost because of being deflected off the film or being obscured by other lines on the oscillogram. The records on the muzzle gages 5 and 12 were particularly bad, firstly, because the strains occurring at the muzzle are practically impact strains of such short duration that they are difficult to photograph at best; and secondly, because of difficulties with the gages such as an apparent shorting out of part of the gage momentarily, or a momentary break in the gage circuit, causing the amplifier to be highly overloaded and the record to go off scale. The muzzle blast may possibly have had an effect on these gages.

13. Before firing was resumed, the timing signal and the reference gage were changed over to the center channel to reduce the possibility of interference between the peaks of the other two records (which for most gage combinations used, occurred at approximately the same time), by connecting them to the two outside channels. Also, in an attempt to improve the photographic recording some Verichrome film was obtained to use in place of the Eastman oscillograph paper.

14. On April 20 after the above changes were made four rounds were fired at the reduced pressure and records were taken on gages 4 and 11, 2 and 9, and 1 and 3. No records were taken on this day on gages 5 and 12 at the muzzle because one of the gages which had broken, was replaced and the cement had not had sufficient time to harden. The four records which were obtained appeared quite satisfactory.

15. A spare set of gages at the muzzle position were cemented in place so that they could be connected up in a short time in case the muzzle gages that were being used, broke or went bad during the next day's firing. At the same time it was felt that valuable information could be obtained by placing some additional gages over the origin of rifling. Consequently a pair of axial and tangential gages were installed in this position, and numbered 15 and 16 respectively.

16. In the next day's firing, April 21, Direx B oscillographic paper was used* and records were taken on gages 4 and 11, 5 and 12, 15 and 16, 4 and 5, and 11 and 12. Instructions had been received at this time that the 115% pressure rounds requested in the directive should be approached gradually because of the danger of blowing up the tube. Consequently, six rounds were fired at 105% and six rounds at 110% pressure before going to the 115% pressure rounds.

17. During this day's firing several gages went bad. Trouble was still experienced in getting records of the muzzle gages because of the difficulties previously mentioned. Therefore, after this day's firing, when replacing the bad gages it was decided to replace all gages in the muzzle group. It was thought that there might be a possibility that the severity of the shock and magnitude of the strains at the muzzle were damaging these gages on the first round fired; hence, it was decided to start the next day's firing on the new gages by using an HE projectile instead of the solid shot, on the presumption that the hollow shell would give lower band pressures and a good record might be obtained.

18. Unfortunately, the first round was missed by an error in triggering the camera and on the second HE round the line to gage 5 was not connected and the record of gage 12 showed the same apparent shorting of the gage** as previously observed.

* This paper was found to be slightly faster than the Eastman paper but not as fast as the Verichrome film. It was felt desirable to use paper if possible, because of the saving of time in developing and general ease of handling.

** The record showed essentially two very sharp vertical deflections: first a minus change of 14 ohms then a plus change of 60 ohms. The latter would correspond to over 500,000 pounds per square inch of stress if it were a true recording of strain. Hence, something undoubtedly went wrong with the gage.

19. On the remainder of the firings on the 22nd records were taken on all the gages, as the pressure was increased to 115%. Additional attempts were made to obtain records on the muzzle gages but all the records were questionable. The records at the other gage positions were, on the whole, quite satisfactory.

Discussion of Results

20. The peak strains observed on all records are grouped according to gage numbers and shown in Tables II to VII. These are the strains at the outer surface of the tube and must not be considered as the highest strains to which the steel of the tube was subjected because the highest strains will occur at the inner wall where they cannot be measured. In addition, there are undoubtedly high concentrations of stress caused by the rifling grooves and boresighting grooves* which are difficult to evaluate. The observed strains were multiplied by an assumed modulus of elasticity of 30,000,000 lbs. per square inch and the results tabulated in the more familiar units of stress, only for the purpose of ease of handling. These would be the correct actual stresses only in the case of simple direct stress parallel to the direction of the gage. The strains as measured are functions of combined axial, tangential, and shear stresses.

21. The shape of the curves obtained from the records of gages along the tube as the projectile passes, (See sketches on Tables II, III, etc.) are extremely interesting and important when studying the effects of the rotating band on the tube. The records of tangential gages are characterized by a sharp high peak of tension as the rotating band passes under the gage, (point A on tangential curves) which immediately drops to the value of strain due to the gas pressure alone as the projectile passes on (point B on tangential curves). The peaks at points A were found to be from 1.2 to 1.9 times the values of B at gage 9 (thick walled section), from 1.5 to 3.8 times the values of B at gage 11 (thin walled section) and possibly four or five times the value of B at the muzzle (gage 12).

22. The records of axial gages over the bore are characterized by three sharp peaks: first a compression peak (point A on axial curves), then a tension peak of about the same order of magnitude (point B on axial curves), then another compression peak somewhat smaller than the previous one (point C on the axial curves). A plausible explanation of these peaks** is as follows: As the projectile is forced through the tube, the walls are unexpanded in front of the rotating band, considerably expanded directly over the rotating band and expanded somewhat less in back of the rotating band, due to the gas pressure. Thus the outer contour of the tube walls, going from front to back and considering the shell as stationary, would appear as (1) a straight section undisturbed, (2) a curve concave outward as the band is approached, (3) a curve convex outward, directly over the band, (4) another concave section as the band is passed, and (5) a straight section of larger diameter than the undisturbed section. As the projectile moves past a fixed gage point, the gage would experience these same changes in contour, in the same order. Since the gage is measuring the axial

* The boresighting grooves on this gun were filed smooth to lessen the possibility of failure of the tube.

** As given by Dr. R. Beeuwkes, Jr. of Watertown Arsenal.

strain in the outer fibres, such a curvature would produce compression when concave and tension when convex outward (considering each thin longitudinal section as a beam bending about its neutral axis). Thus the three peaks as observed on the records appear very reasonable. The second compression peak is less than the first because the curvature is less due to the gas pressure in back of the projectile.

23. In Table VIII are tabulated all of the firing data together with the observed stresses of the reference gage, No. 8. These data are grouped according to increasing charge, and within each group of one charge, the rounds are arranged in order of increasing velocity. The last column in this table is the ratio of the observed tangential stress to the copper pressure as determined by the average of two medium caliber copper gages. This ratio was plotted against round number (Figure 3) in order to get a better picture of the dispersion. Theoretically the ratio should be a constant and equal to 0.73 (assuming that the true pressure equals 1.2 times the copper pressure) providing that at the time of the maximum pressure, the gun tube could be considered as a simple open cylinder. Apparently the tangential stress is reduced by the fact that open cylinder conditions do not exist at this time, as evidenced by the stresses exhibited by the axial gages. The observed dispersion of points on Figure 3 may be partly due to the dispersion of the copper gages, partly to the effects of variation of the axial force, and partly to the accidental error of the observations. The overall accuracy of the measurements is estimated as 5%.

24. In connection with the axial forces existing, the records taken on the gages over the forcing cone (15 and 16) are especially interesting. It may be seen from Figure 4 and Tables V and VI, that this section is under tension both axially and tangentially at the time of engraving. Likewise the axial gage No. 1 over the chamber is under tension and these peaks correspond to the dip observed in the early part of the record of the tangential gage No. 8 over the chamber. The tension in gages 15 and 16 appears reasonable due to the bulging of the section of the tube in the vicinity of the forcing cone during engraving, and the tension in the gage 1 is probably due to such effects as acceleration of the tube rearward by the pressure on the breech or possibly a momentary decrease in the acceleration of the projectile during engraving. Such an axial force would naturally result in a decrease in the tangential strain according to Poisson's ratio to produce the dip in the tangential strain record mentioned above.

25. However, it will be observed that, at the time of maximum pressure (as shown by gage 8), whereas axial gage 1 has changed to compression as would be expected under open cylinder conditions, point B on axial gage 15 is still under considerable tension. This may be an indication that the shell is still close enough to the origin of rifling at the time of maximum pressure so that the bulging due to the rotating band still affects gages 15 and 16.

26. While no calculations of band pressures are included herein, the indications are that they are of the order of sixty or seventy thousand pounds per square inch at the thick walled section and twenty to thirty thousand pounds per square inch near the muzzle. Therefore, it becomes important in gun design that due cognizance be taken of the pressures of the rotating band as well as the gas pressures.

27. Other important information is now being obtained from a more complete study of the film records. When this becomes available it will be submitted as an addendum to this report.

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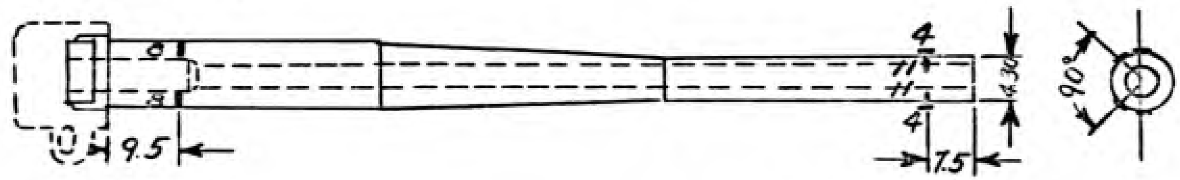
TABLE I

LIST OF GAGES USED ON EACH ROUND.
76MM M1E2 STRAIN MEASUREMENTS

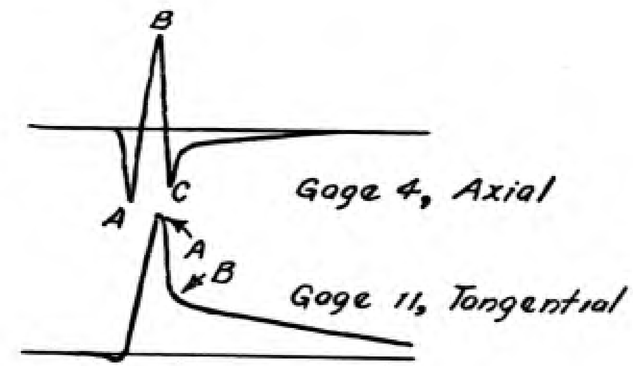
DATE	RD. NO.	GAGES			DATE	RD. NO.	GAGES		
4/18/43	5	4	11	8	4/22/43	30	5	8	12
	6	4	11	8		31	5	8	12
	7	2	9	8		32	5	8	12
	8	5	12	8		33	5	8	12
	9	5	12	8		34	5	8	12
	10	5	12	8		35	4	8	11
	11	4	11	8		36	1	8	3
	12	2	9	8		37	1	8	3
	13	1	3	8		38	1	8	3
	14	4	5	8		39	15	8	16
						40	3	8	7
4/20/43	15	4	8	11		41	3	8	7
	16	4	8	11		42	3	8	7
	17	2	8	9		43	4	8	11
	18	1	8	3		44	4	8	11
						45	4	8	11
4/21/43	19	5	8	12		46	5	8	12
	20	5	8	12		47	1	8	3
	21	4	8	11		48	1	8	3
	22	4	8	5		49	2	8	9
	23	11	8	12		50	2	8	9
	24	11	8	12		51	15	8	16
	25	15	8	16		52	15	8	16
	26	4	8	11		53	16	8	3
	27	11	8	12					
	28	11	8	12					
	29	11	8	12					

SUMMARY OF PEAK STRAINS AT GAGES 4 AND 11.
76MM GUN M1A2

Location of Gages:



Typical Curves



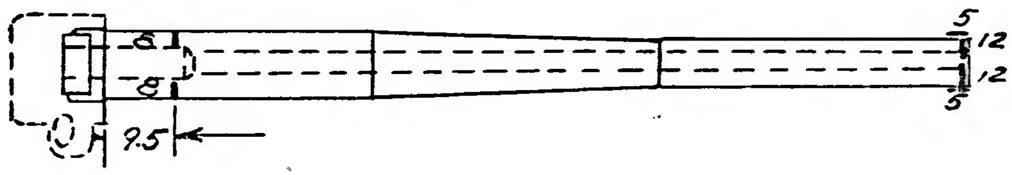
Date 1943	Gun Rd. No.	Per cent Charge	Velocity f/s.	Dia. of Rotating Band, ins.	Ref. Gage 8	Observed Peak Stresses(1) Gage 4 A	Gage 4 B	Gage 4 C	Gage 11 A	Gage 11 B
4-18	5	75	2298	3.090	18,000	-20,300	———	-17,900	31,200	12,800
	6	"	2283	3.092	16,500	-15,900	14,500	-13,900	41,400	11,100
4-20	15	"	———	3.094	20,200	-23,100(2)	off the film	-23,100	39,000	14,300
	16	"	2335	3.090	19,300	-23,600	32,100	-23,400	38,200	15,100
4-18	11	100	2595	3.097	25,000	-15,300	16,800	-12,300	31,100	12,600
4-21	21	"	2615	3.095	26,400	-15,400(2)	27,700	-21,600	42,200	14,300
	26	"	2577	3.091	23,600	———	———	———	15,150(2)	12,150(2)
4-22	43	"	2614	———	29,500	-10,300	16,600	-10,300	30,400	14,500
	35	105	2679	3.093	30,400	———	———	———	———	———
	44	115	2733	3.093	32,000	- 8,550	8,300	- 8,050	23,200	15,300
	45	"	2753	3.093	34,100	-15,300(3)	8,300(3)	- 7,560(3)	26,600	14,500

(1) The observed strains have been multiplied by E = 30,000,000 lb/in^2. Minus sign indicates compressive strain. All strains are measured on the outer surface; the corresponding strains of the inner wall will be considerably higher.
(2) Film record not clear.
(3) These peaks do not correspond to the diagram given above. There were 5 peaks on this record instead of 3. The first, fourth, and fifth are given.

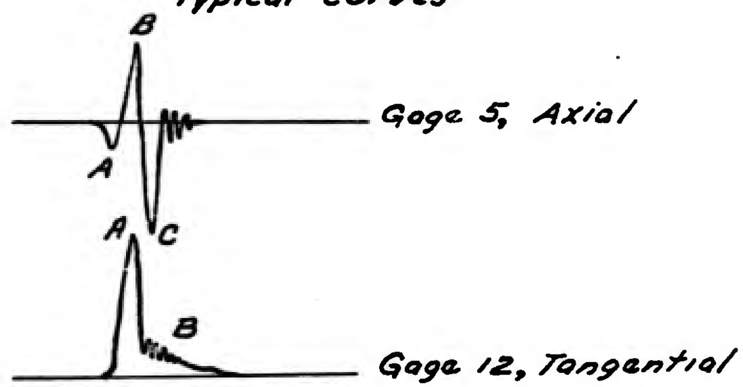
TABLE III

SUMMARY OF PEAK STRAINS AT GAGES 5 AND 12
76MM GUN M1E2

Location of Gages:



Typical Curves



Date	Gun Rd. No.	Per-cent Charge	Velocity f/s.	Dia. of Rotating Band, ins.	Ref. Gage 8	Observed Peak Stresses(1) Gage 5 A	Gage 5 B	Gage 5 C	Gage 12 A	Gage 12 B	Remarks
4-18	8	75	2293	3.091	16,700	-13,800	12,900	-16,700	(2) ———	———	Peaks on 5 very questionable
	9	"	2277	3.094	16,300	- 8,700	30,300	-18,800	———	———	"
4-21	19	"	2348	3.093	19,700	———	10,700	- 9,900	53,400	9,800	"
4-22	32	"	2346	3.096	18,600	———	71,100	-48,900	———	———	"
4-22	30	85HE	———	———	———	———	———	———	———	———	Poor Trigger Timing
	31	"	2499	———	18,300	Not Connected			———	———	
4-18	10	100	2590	3.090	24,200	———	———	———	———	———	High Peaks overloaded Amplifiers
4-21	20	"	2583	3.092	24,600	-10,000	16,700	-23,600	38,400	9,100	Gage 5 Record Not Clear
4-22	33	"	2588	3.095	23,500	0	45,400	-63,600	———	———	
	34	105	2684	3.095	28,900	0	41,600	-41,600	———	———	
	46	115	2751	3.093	32,800	———	———	———	———	———	

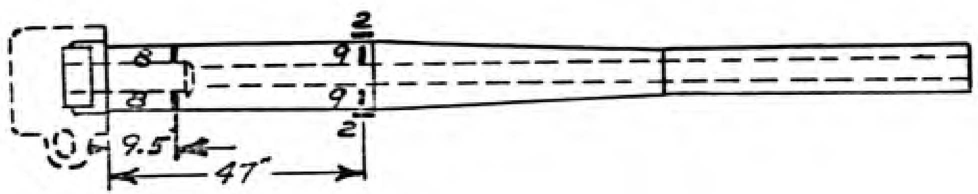
(1) The observed strains have been multiplied by E= 30 x 10^6 lb./in.^{2} Minus indicates compression. All strains are measured on the outer surface; the corresponding strains at the inner wall will be considerably higher.

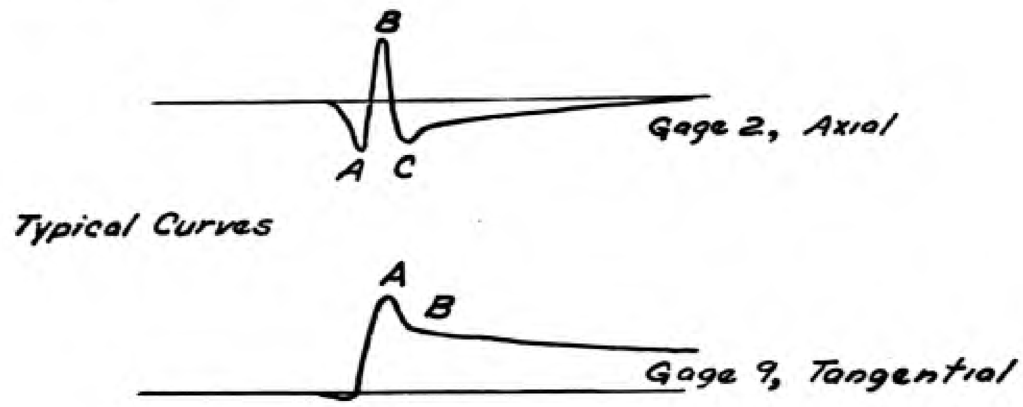
(2) Most of the records for Gage 12 were lost because of an apparent shorting of the gage. Gage was found to be [illegible].

TABLE IV

SUMMARY OF PEAK STRAINS AT GAGES 2 AND 9
76 MM. GUN M1A2

Location of Gages:





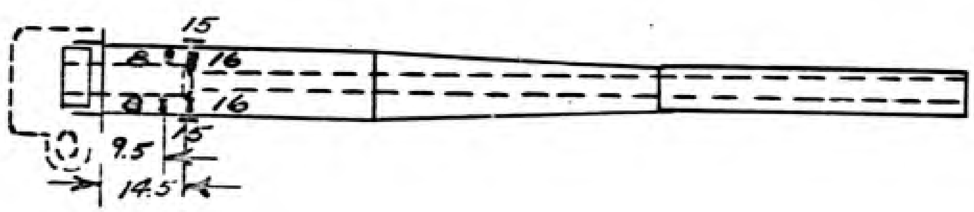
Date	Gun Rd. No.	Per-cent Charge	Velocity f/s.	Dia. of Rotating Band, ins.	Observed Peak Stresses(1) Ref. Gage 8	Gage 2 A	Gage 2 B	Gage 2 C	Gage 9 A	Gage 9 B
4-18	7	75	2595	3.094	15,900	- 7,200	9,000	-5,000	16,400	10,800
4-20	17	75	2347	3.095	18,400	-10,300	16,600	-7,500	22,900	12,100
4-13	12	100	2578	3.097	22,600	- 7,100	8,700	-4,100	19,400	15,000
4-22	49	115	2756	3.093	32,500	- 9,900	11,200	-4,400	25,400	17,300
	50	115	2754	3.092	30,400	- 4,300	5,700	-2,900	19,100	16,100

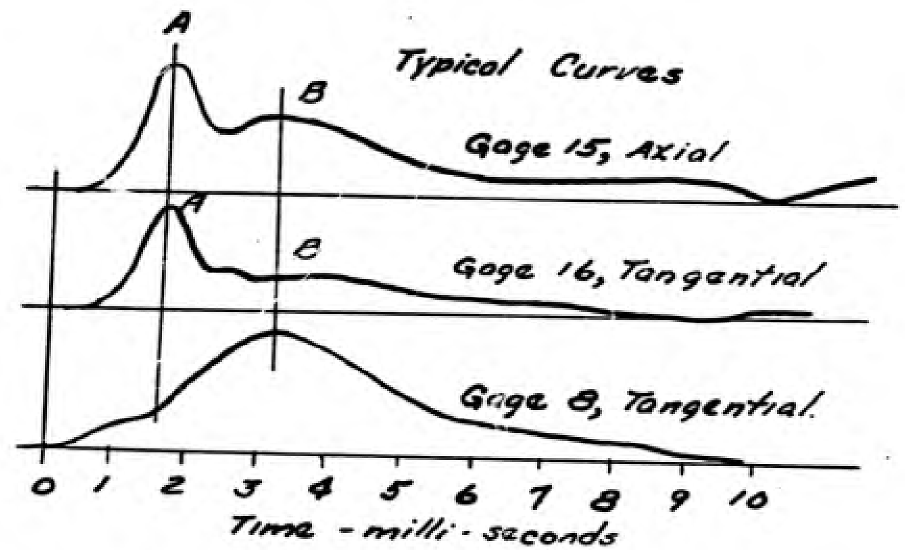
(1) The oberved strains have been multiplied by $E = 30 \times 10^6$ lb./in.^{2} Minus indicates compression. All strains are measured on the outer surface; the corresponding strains at the inner wall will be considerably higher.

TABLE V

SUMMARY OF PEAK STRAINS AT GAGES 15 AND 16
76 MM GUN M1E2

Location of Gages:





Date	Gun Rd. No.	Per Cent Charge	Velocity f/s.	Dia. of Rotating Band	Observed Peak Stresses(1) Ref. Gage 8	Gage 15 A	Gage 15 B	Gage 16 A	Gage 16 B
4-21	25	100	2613	3.095	26,500	23,700	13,600	20,300	5,800
4-22	39	110	2720	3.094	30,900	25,600	15,200	23,900	8,200
4-22	51	115	2752	3.092	31,000	15,800	14,400	15,600	7,600
	52	115	2752	3.093	31,800	20,800	15,200	20,700	7,500

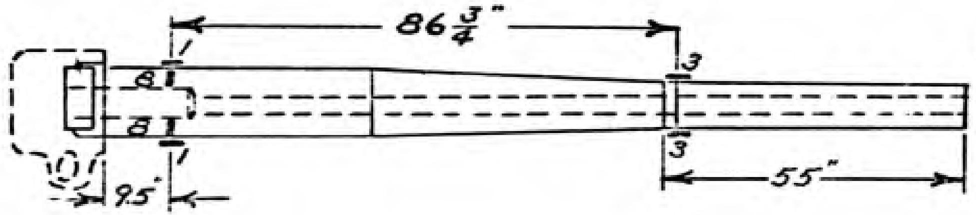
(1) The observed strains have been multiplied by E = 30 x 10^6 lb./in.^{2} All strains are measured at the outer surface; the corresponding strains at the inner wall will be considerably higher.

(2) Points "B" for Gages 15 & 16 correspond to the instant of maximum Strain on the reference gage.

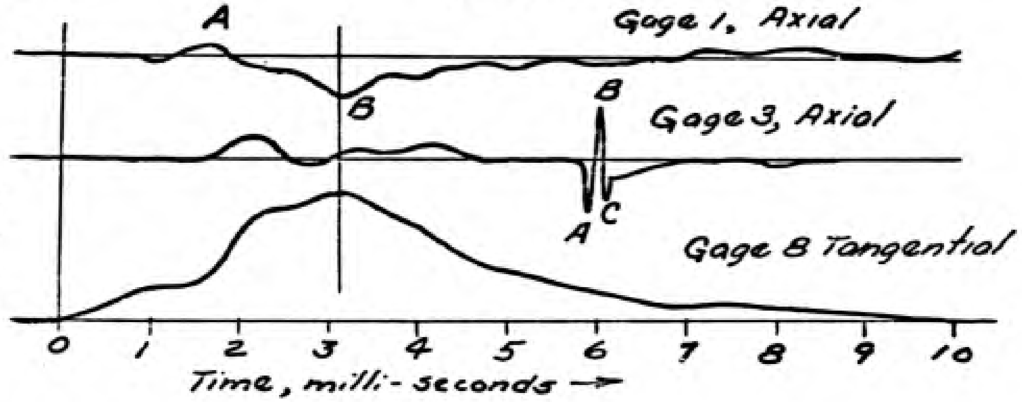
TABLE VI

SUMMARY OF PEAK STRAINS AT GAGES 1 AND 3
76MM GUN M1E2

Location of Gages:



Typical Curves



Date 1943	Gun Rd. No.	Per-cent Charge	Velocity f/s.	Dia. of Rotating Band	Ref. Gage 8	Observed Peak Stresses(1) Gage 1 A	Gage 1 B(2)	Gage 3 A	Gage 3 B	Gage 3 C
4-20	18	75	2331	3.094	17,900	———	(-3,200) -2,900	-13,800	11,500	- 9,900
4-18	13	100	2589	3.094	23,400	1,500	-5,400	-12,900	13,200	- 9,800
4-22	36	105	2677	3.095	30,600	———	-3,200	———	———	———
"	37	110	2722	3.094	29,400	———	(-9,100) -8,700	-13,000	12,100	-12,100
"	38	110	2740	3.095	32,200	2,400	-8,500	-13,900	11,600	- 9,400
"	47	115	2755	3.095	31,500	2,200	-7,300	-14,100	7,700	-10,600
"	48	115	2740	3.092	29,800	2,000	-7,200	- 8,900	3,200	- 6,100

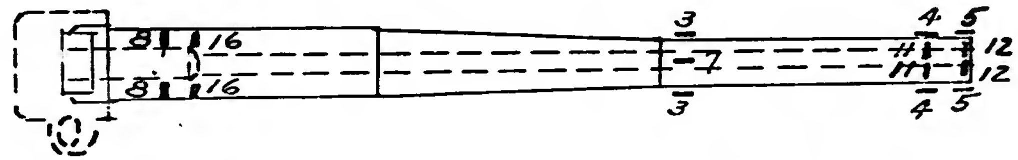
(1) The observed strains have been multiplied by $E = 30 \times 10^6$ lb./in.^{2} All strains are measured at the outer surface; the corresponding strains at the inner wall will be considerably higher. Minus sign indicates compression.

(2) Point "B" on Gage 1 corresponds to the instant of maximum pressure on the reference gage. Figures in parentheses are the maxima when they did not occur at this instant.

TABLE VII

SUMMARY OF PEAK STRAINS WHEN GAGE COMBINATIONS
4 & 5, 11 & 12, 3 & 7, and 3 & 16 WERE USED

Location of Gages:



Date	Gun Rd. Number	Percent Charge	Velocity f/s.	Dia. of Rotating Band	Ref. Gage #8	Gage No.	A(3)	B	C	Gage No.	A	B	C
							Observed Peak Stresses(1)						
4-18	14	100	2592	3.095	22,400	4	- 7,100(2)	11,200	-10,300(2)	5	———	———	———
4-21	22	100	2598	3.093	25,400	4	-17,200	20,300	-16,200	5	-4,200	69,000	off the film(2)
4-21	23	100	2598	3.092	24,900	11	34,700	12,100	———	12	53,400(2)	———	———
"	24	100	2587	3.091	23,900	11	37,200	14,100	———	12	19,300	———	———
"	27	105	2684	3.095	29,500	11	55,700	14,600	———	12	No Good		
"	28	105	2688	3.094	27,700	11	off the film	16,700(2)	———	12	No Good		
"	29	105	2686	3.095	29,600	11	103,000	40,000	———	12	No Good		
4-22	40	110	2719	3.095	30,500	3	-21,500(2)	21,100(2)	-18,200	7	-10,800	14,600	-8,200
"	41	110	2699	3.093	29,700	3	-20,300	18,900	-16,300	7	off the film	47,000	off the film
"	42	110	2726	3.095	29,500	3	-11,300	16,800	-11,200	7	———	———	———
4-22	53	115	2737	3.092	28,400	3	-11,300	6,200	- 8,100	16	17,200	7,200	———

(1) The observed strains have been multiplied by $E = 30 \times 10^6$ lb. per sq. in. Minus indicates compression. All strains are measured on the outer surface; the corresponding strains at the inner wall will be considerably higher.

(2) Record not clear.

(3) Letters A, B, and C refer to points on Tables II, III, IV, V, and VI.

[redacted]

A

TABLE VIII

TABULATION OF FIRING DATA AND PEAK STRAINS ON
REFERENCE GAGE 8
76 [redacted] GUN [redacted]

Date 1943	Gun Rd. No.	Powder %	Charge oz.	Muzzle Velocity f/s	Weight of Projectile lbs.	Dia. of Rotating Band in.	Powder Pressure (Coppers) 1000 p.s.i. P_{cu}	Tangential Stress Gage 8 1000 p.s.i. S	Ratio S/P_{cu}
4/18	9	75	50.75	2277	15.06	3.094	27.2	16.3	.60
"	7	75	"	2282	15.09	3.094	26.7	15.9	.60
"	6	75	"	2283	15.07	3.092	26.3	16.5	.63
"	8	75	"	2293	15.05	3.091	27.5	16.7	.61
"	5	75	"	2298	15.06	3.090	28.1	18.0	.64
4/20	18	75	"	2331	15.09	3.094	28.9	17.9	.62
"	16	75	"	2335	15.06	3.090	30.0	19.3	.64
4/22	32	75	"	2346	15.05	3.096	29.7	18.6	.63
4/20	17	75	"	2347	15.02	3.095	29.8	18.4	.62
4/21	19	75	"	2348	14.94	3.093	31.1	19.7	.63
4/20	15	75	"	----	15.13	3.094	31.5	20.2	.64
4/22	30	85	50.0	----	12.72	----	25.0	----	----
"	31	85	54.0	2499	12.72	----	----	18.3	----
4/21	26	100	57.0	2577	14.91	3.091	34.8	23.6	.68
4/18	12	100	"	2578	15.05	3.097	37.0	22.6	.60

[redacted]

[redacted]

"	6	75	"	2283	15.07	3.092	26.3	[illegible]	[illegible]
"	8	75	"	2293	15.05	3.091	27.5	16.7	.61
"	5	75	"	2298	15.06	3.090	28.1	18.0	.64
4/20	18	75	"	2331	15.09	3.094	28.9	17.9	.62
"	16	75	"	2335	15.06	3.090	30.0	19.3	.64
4/22	32	75	"	2346	15.05	3.096	29.7	18.6	.63
4/20	17	75	"	2347	15.02	3.095	29.8	18.4	.62
4/21	19	75	"	2348	14.94	3.093	31.1	19.7	.63
4/20	15	75	"	----	15.13	3.094	31.5	20.2	.64
4/22	30	85	50.0	----	12.72	----	25.0	----	----
"	31	85	54.0	2499	12.72	----	----	18.3	----
4/21	26	100	59.0	2577	14.91	3.091	34.8	23.6	.68
4/18	12	100	"	2578	15.05	3.097	37.0	22.6	.60
[illegible]	[illegible]	100	"	[illegible]	[illegible]	3.092	36.6	24.6	.63
"	24	100	"	2587	15.03	3.091	37.2	23.9	.64
4/22	33	100	"	2588	15.04	3.095	38.3	23.5	.61
4/18	13	100	"	2589	15.01	3.094	38.5	23.4	.61
"	10	100	"	2590	15.14	3.090	38.6	24.2	.63
"	14	100	"	2592	15.05	3.095	38.8	22.4	.58
"	11	100	"	2595	----	3.097	39.1	25.0	.64
4/21	23	100	"	2598	15.02	3.092	37.9	24.9	.66
"	22	100	"	2598	15.08	3.093	38.5	25.4	.66
"	25	100	"	2613	15.07	3.095	41.0	26.5	.65
4/22	43	100	"	2614	15.00	----	42.1	29.5	.70

B

[redacted]

TABLE VIII (cont.)

Date 1943	Gun Rd. No.	Powder Charge %	oz.	Muzzle Velocity f/s	Weight of Projectile lbs.	Dia. of Rotating Band in.	Powder Pressure (Coppers) 1000 p.s.i. P_{cu}	Tangential Stress Gage 8 1000 p.s.i. S	Ratio S/P_{cu}
4/21	21	100	59.0	2615	15.08	3.095	39.1	26.4	.68
4/22	36	105	61.13	2677	15.10	3.095	44.3	30.6	.69
"	35	105	"	2679	15.07	3.093	43.9	30.4	.69
4/21	27	105	"	2684	15.05	3.095	44.0	29.5	.67
4/22	34	105	"	2684	15.08	3.095	44.2	28.9	.65
4/21	29	105	"	2686	15.02	3.095	43.9	29.6	.68
"	28	105	"	2688	14.95	3.094	43.9	27.7	.63
4/22	41	110	62.30	2699	15.15	3.093	45.2	29.7	.66
"	40	110	"	2719	15.03	3.095	46.2	30.5	.66
"	39	110	"	2720	15.09	3.094	46.3	30.9	.67
"	37	110	"	2722	15.04	3.094	46.5	29.4	.63
"	42	110	"	2726	15.07	3.095	45.3	29.5	.65
"	38	110	"	2740	15.05	3.095	48.4	32.2	.67
4/22	44	115	63.40	2733	15.07	3.093	45.2	32.0	.71
"	53	115	"	2737	15.03	3.092	46.5	28.4	.61

D

[redacted]

[redacted]

[redacted]

4/22	36	105	61.13	2677	15.10	3.093	[illegible]	[illegible]	[illegible]
"	35	105	"	2679	15.07	3.093	43.9	30.4	.69
4/21	27	105	"	2684	15.05	3.095	44.0	29.5	.67
4/22	34	105	"	2684	15.08	3.095	44.2	28.9	.65
4/21	29	105	"	2686	15.02	3.095	43.9	29.6	.68
"	28	105	"	2688	14.95	3.094	43.9	27.7	.63
4/22	41	110	62.30	2699	15.15	3.093	45.2	29.7	.66
"	40	110	"	2719	15.03	3.095	46.2	30.5	.66
"	39	110	"	2720	15.09	3.094	46.3	30.9	.67
"	37	110	"	2722	15.04	3.094	46.5	29.4	.63
"	42	110	"	2726	15.07	3.095	45.3	29.5	.65
"	38	110	"	2740	15.05	3.095	48.4	32.2	.67
4/22	44	115	63.40	2733	15.07	3.093	45.2	32.0	.71
"	53	115	"	2737	15.03	3.092	46.5	28.4	.61
"	43	115	"	2740	15.07	3.092	44.8	29.8	.67
"	46	115	"	2751	15.14	3.093	47.9	32.8	.69
"	52	115	"	2752	15.08	3.093	46.7	31.8	.68
"	51	115	"	2752	15.08	3.092	47.7	31.0	.65
"	45	115	"	2753	15.02	3.093	47.6	34.1	.72
"	50	115	"	2754	15.07	3.092	45.2	30.4	.67
"	47	115	"	2755	15.03	3.095	47.6	31.5	.66
"	49	115	"	2756	15.02	3.093	46.7	32.5	.70

Powder, FNH Lot 8007-42

[redacted]

B

NOT REPRODUCIBLE

NOT REPRODUCIBLE

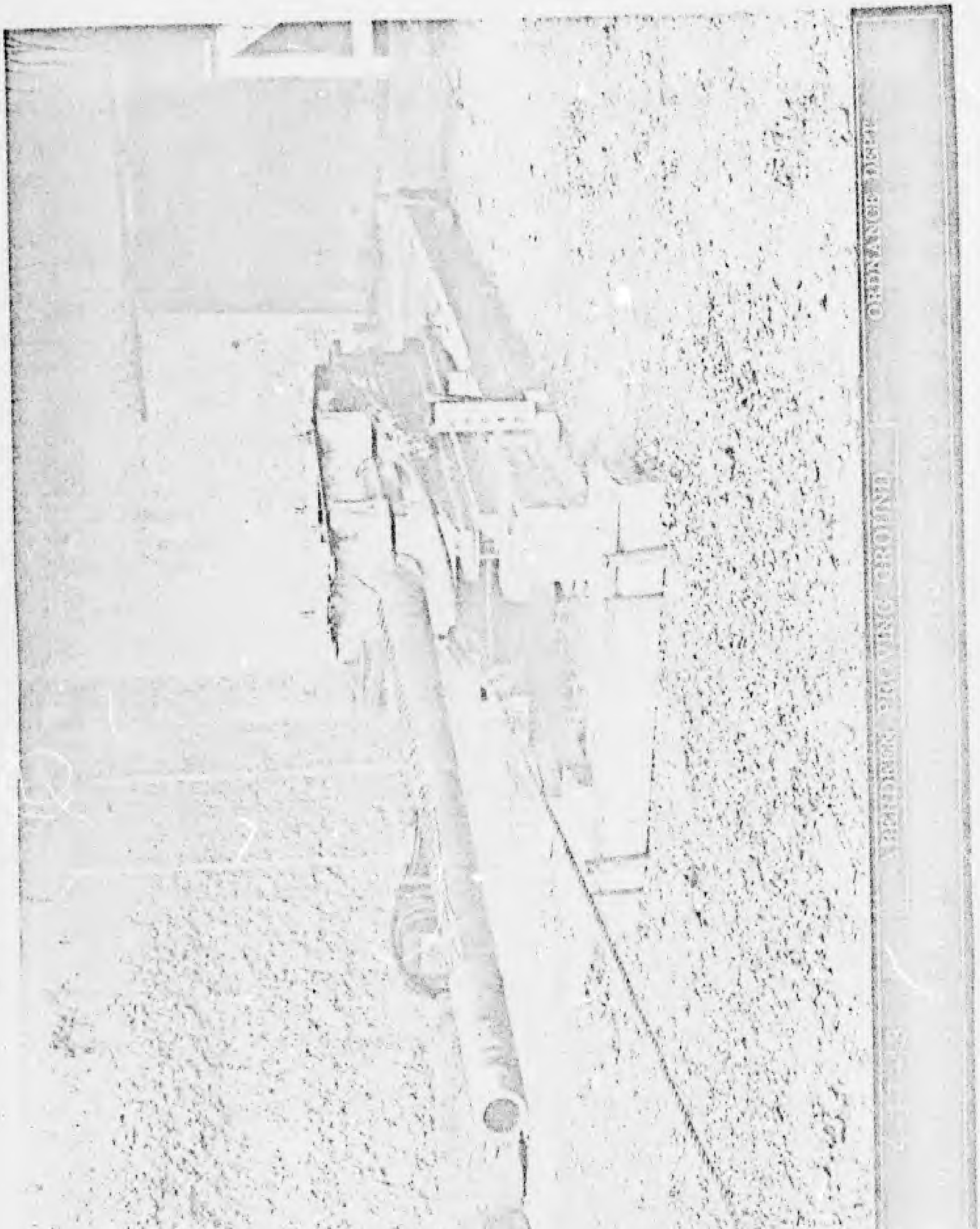
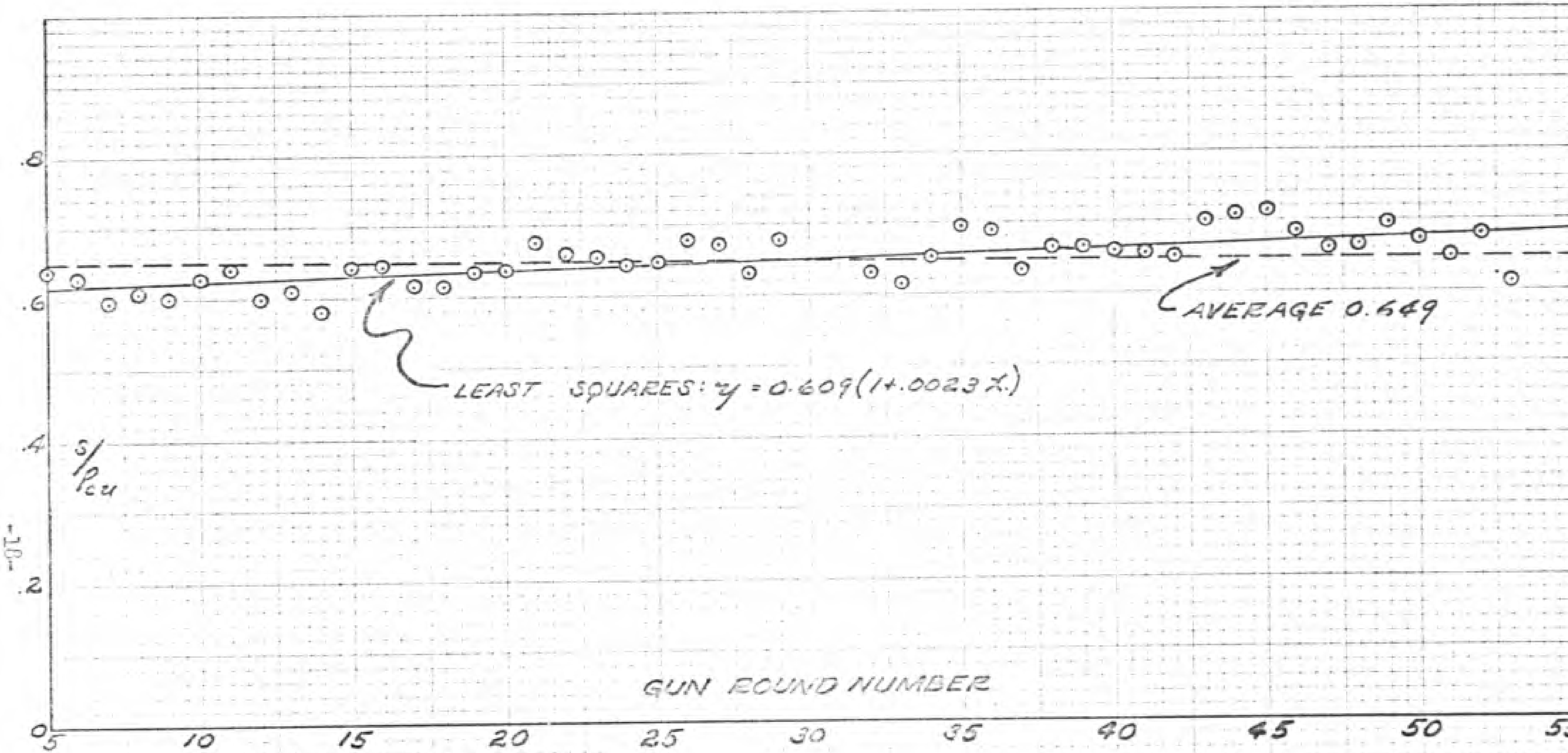


Figure 1

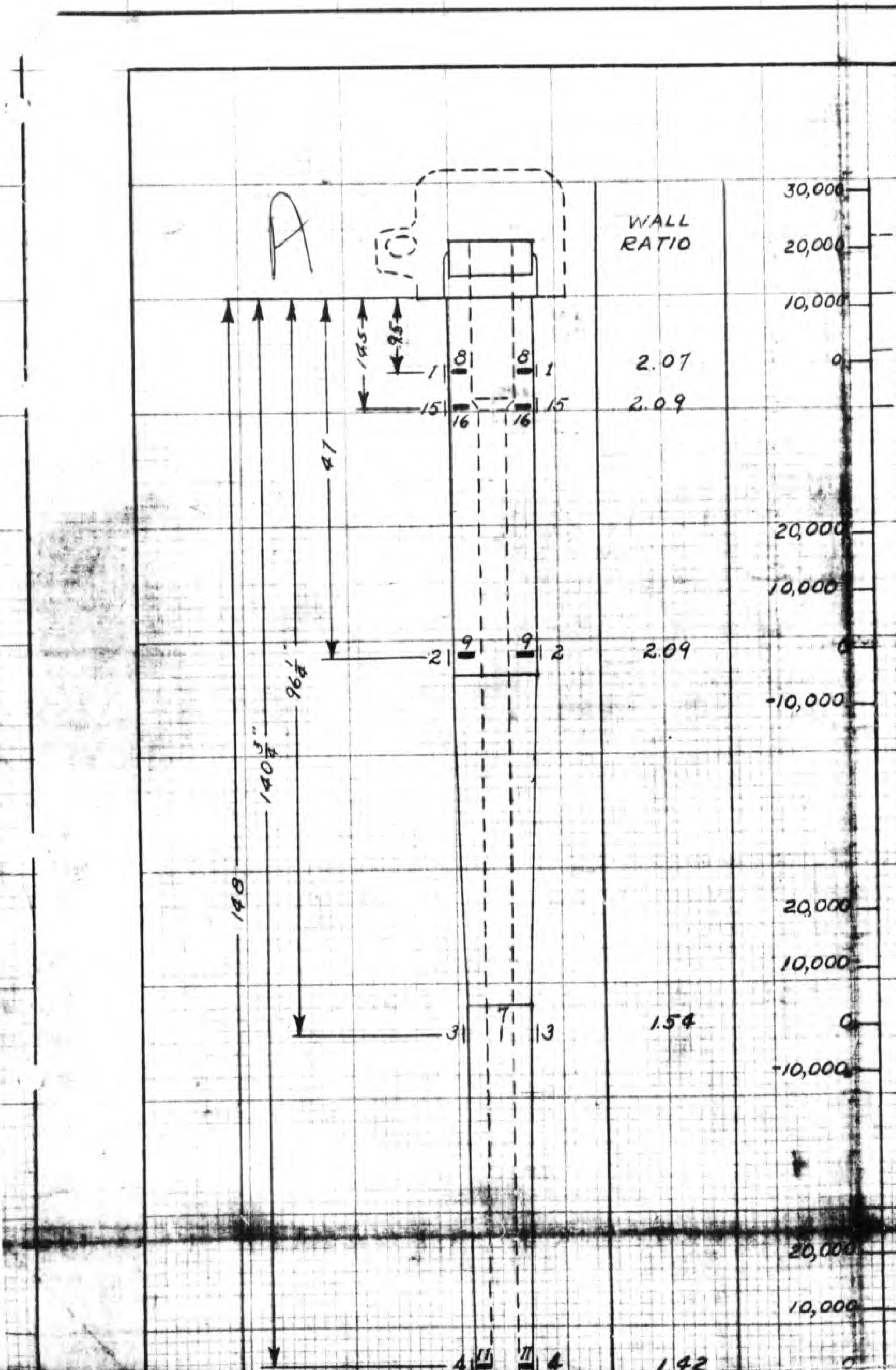
NOT REPRODUCIBLE

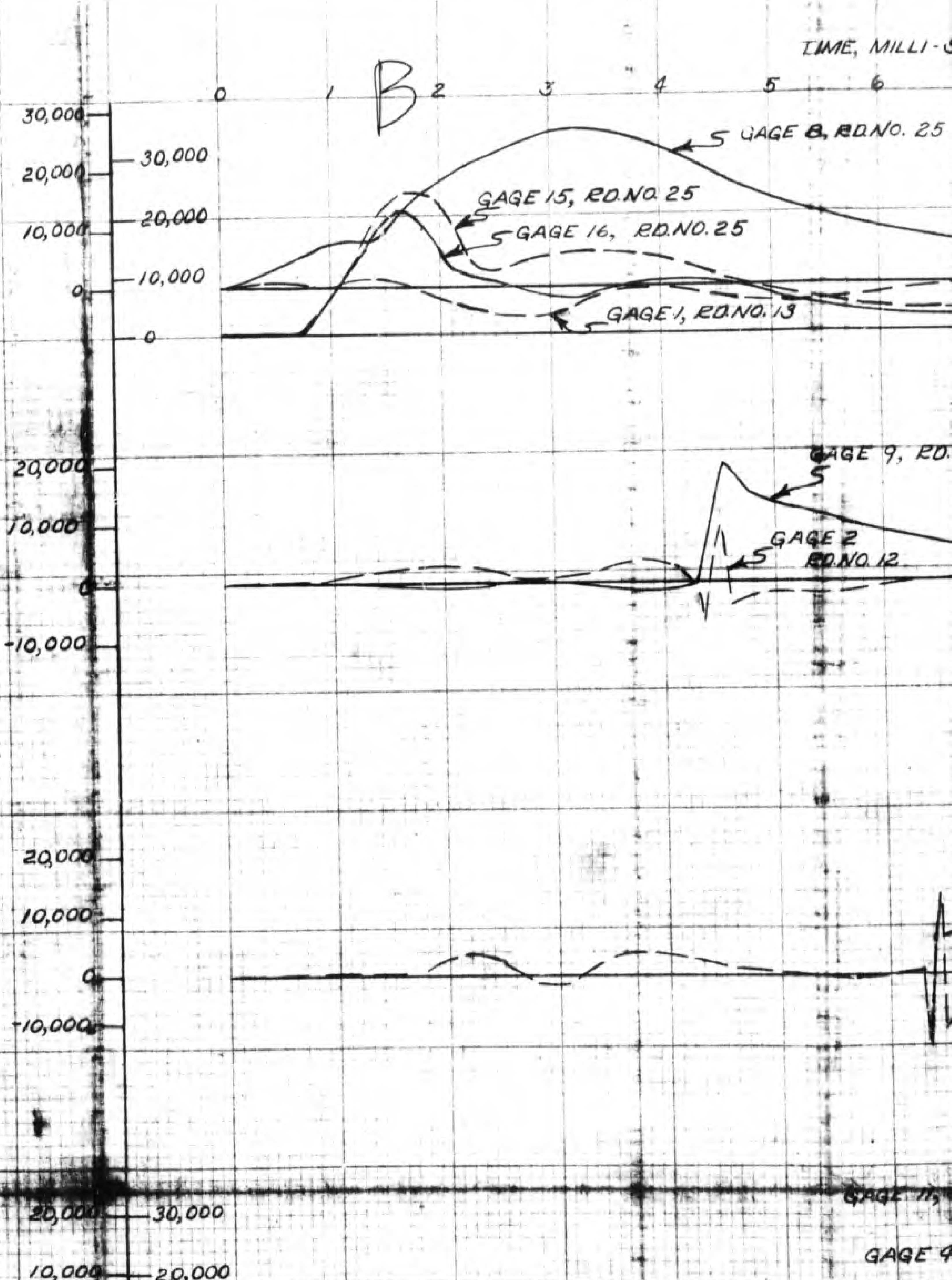
Figure 2

NOT REPRODUCIBLE

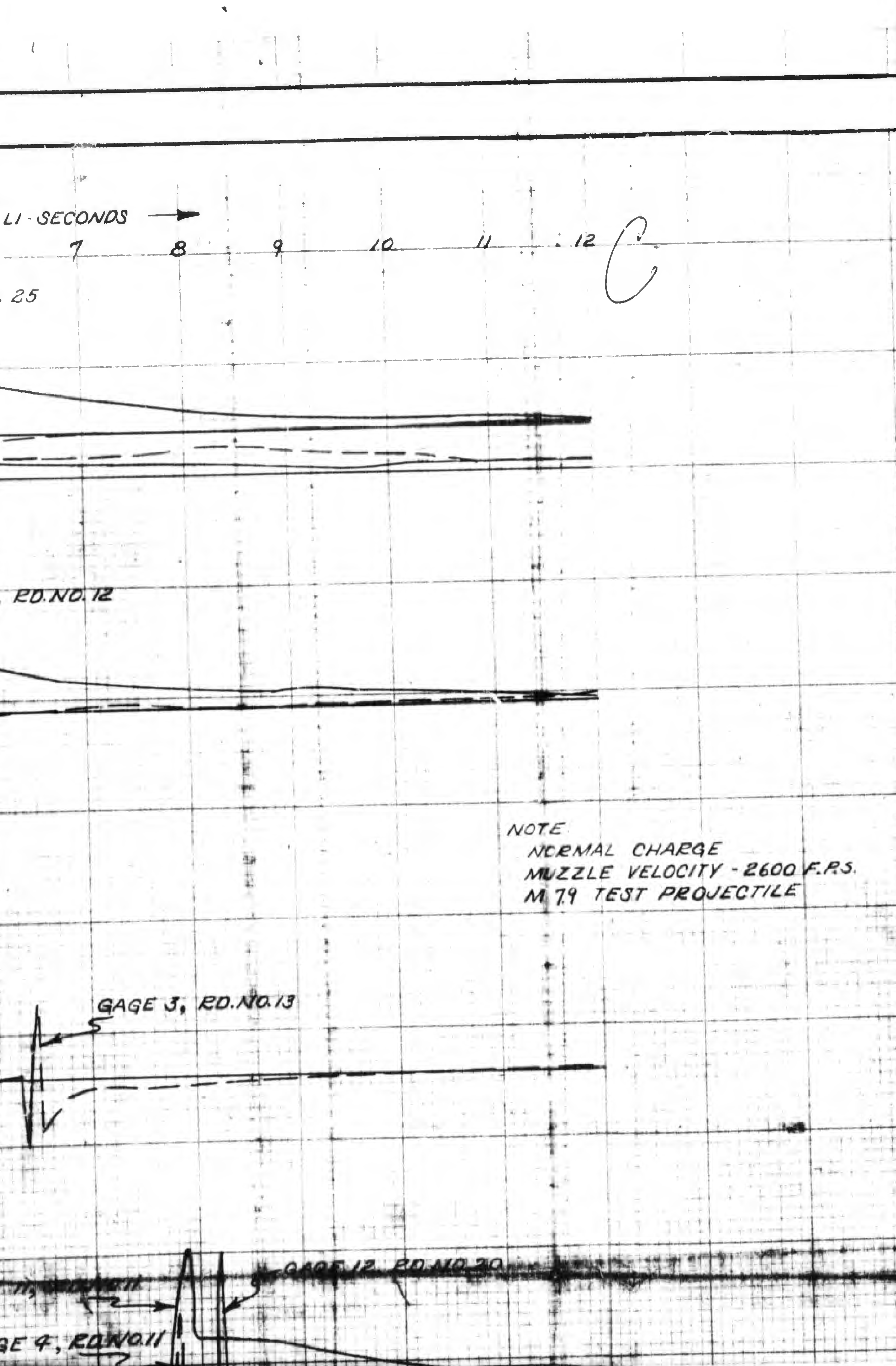


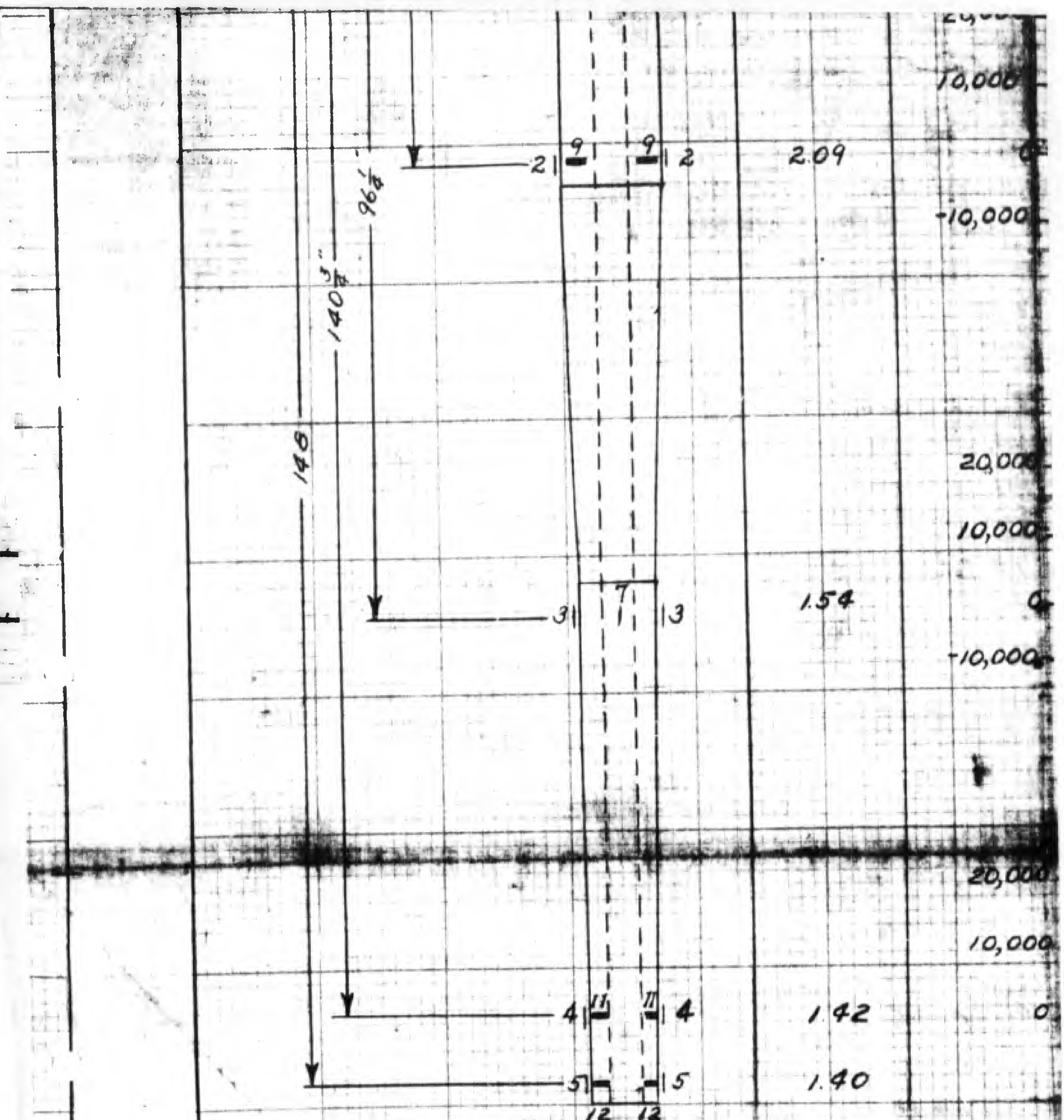
ABERDEEN PROVING GROUND BALLISTIC RESEARCH LABORATORY ORDNANCE ENGINEERING BRANCH	RATIO OF TANGENTIAL STRESS TO COPPER PRESSURES 76 M/M GUN M1E2
DRAWN-PH. | 4-12-43 | APPROVED-	REF. REPORT NO. | FIG. 3


A
WALL RATIO
2.07
2.09
2.09
1.54
1.42
.95
14.5
47
96 1/4
140 3/4"
148
30,000
20,000
10,000
0
-10,000

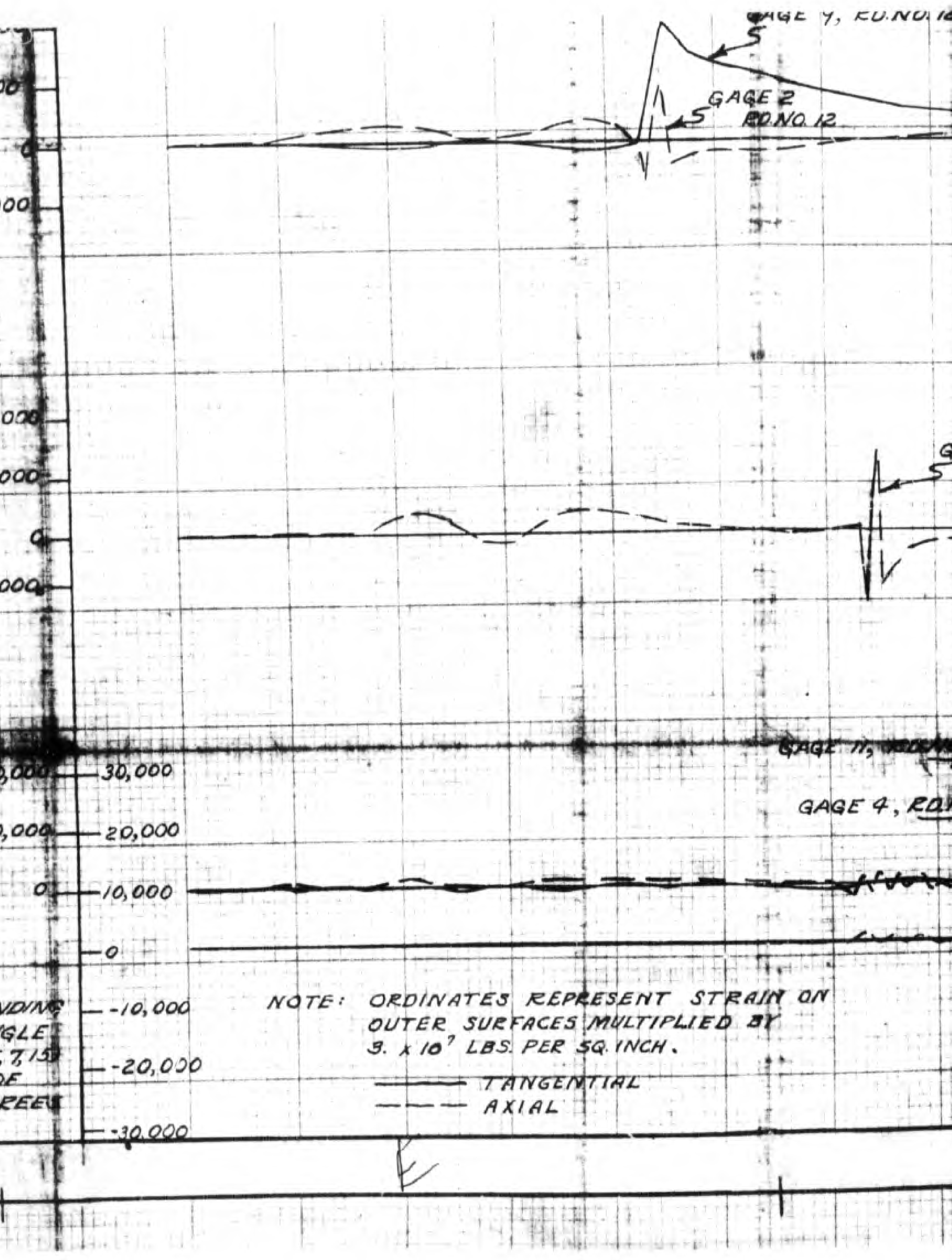


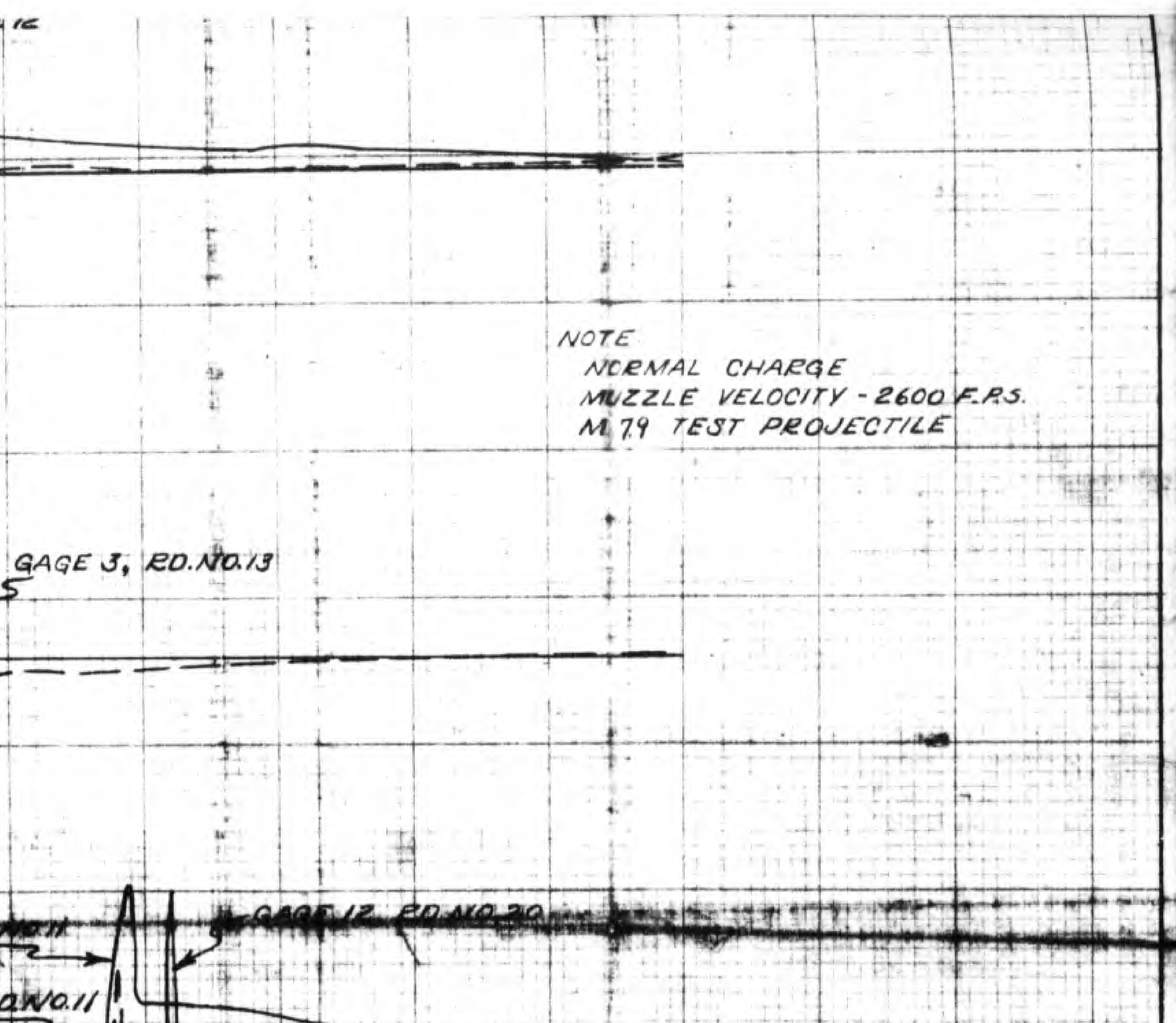
B
TIME, MILLI-S
0
1
2
3
4
5
6
30,000
20,000
10,000
0
30,000
20,000
10,000
0
GAGE 8, RD.NO. 25
GAGE 15, RD.NO. 25
GAGE 16, RD.NO. 25
GAGE 1, RD.NO. 13
20,000
10,000
0
-10,000
GAGE 9, RD.
GAGE 2
RD.NO. 12
20,000
10,000
0
-10,000
20,000
10,000
30,000
20,000
GAGE 4


LI-SECONDS
7
8
9
10
11
12
C
.25
RD.NO.12
NOTE
NORMAL CHARGE
MUZZLE VELOCITY - 2600 F.P.S.
M 79 TEST PROJECTILE
GAGE 3, RD.NO.13
GAGE 12, RD.NO.20
GE 4, RD.NO.11



NOTE: THERE ARE TWO GAGE ELEMENTS CORRESPONDIN[G] TO EACH GAGE NUMBER AND USED AS A SINGLE GAGE. THE ELEMENTS OF AXIAL GAGES (1, 2, 3, 4, 5, 7, 15) ARE DIAMETRICALLY OPPOSITE. THE ELEMENTS OF TANGENTIAL GAGES (8, 9, 11, 12, 16) ARE AT 90 DEGREES


GAGE 9, RD. NO. 12
GAGE 2
RD. NO. 12
GAGE 11
GAGE 4, RD
30,000
20,000
10,000
0
-10,000
-20,000
-30,000
NOTE: ORDINATES REPRESENT STRAIN ON OUTER SURFACES MULTIPLIED BY 3. x 10^7 LBS. PER SQ. INCH.
TANGENTIAL
AXIAL


NOTE
NORMAL CHARGE
MUZZLE VELOCITY - 2600 F.P.S.
M 79 TEST PROJECTILE
GAGE 3, RD.NO.13
GAGE 12, RD.NO.20
GAGE 5, RD.NO. 20
STRAIN RECORDS ON 76 M/M, M1E2
ABERDEEN PROVING GROUND
BALLISTIC RESEARCH LABORATORY
ORDNANCE ENGINEERING BRANCH
DRN. P.H. 5-26-43 APPROVED
REF. REPORT NO.
FIG. 4

Appendix I

DESCRIPTION OF STRAIN RECORDING EQUIPMENT

Gages

1. The strain gages used for recording transient strains on gun carriages, tubes, etc. are resistance type gages* consisting of a grid of very fine wire (approximately .001 " diameter) bonded to a piece of very thin paper which in turn is cemented to the surface upon which the strain is to be measured. The wire is a special alloy selected for its strain sensitivity and low temperature coefficient of resistance. Each gage element has a resistance of approximately 500 ohms (the 1 inch gage) and a strain sensitivity of about 3.4. The strain sensitivity is the unit resistance change per unit of strain. Hence, these gages will exhibit a change of about 1.7 ohms for a strain of .001 inch per inch or an equivalent stress of 30,000 lbs. per square inch in steel. The gages are sufficiently flexible so that they may be used on curved or warped surfaces. The strain sensitivity factor is given by the manufacturer of these gages with an accuracy of about 1%.

2. Since the gages are rather fragile, the lead wires must be held quite firmly in place to prevent them from exerting any pull on the gage due to their movement during firing or due to the gun's blast. The method of making connections that is usually used is as follows:

3. The heavy rubber covered shielded leads which go to the recording equipment are terminated at a panel board (usually consisting of Jones plugs or any good quality connectors), which is clamped or bolted rigidly to the gun as near to the gages as practicable. Soldered connections are then made from the plugs to the gages by means of small insulated wires which are held firmly in place by means of tape and/or cement.

Strain Gage Circuit

4. The circuit that is used for transient strain recording consists simply of a steady supply of DC voltage (usually three or four "B" batteries), connected through a ballast resistance (to control the sensitivity and limit the current) and the strain gage, in series. If one side of the gage is at ground potential then the voltage across the gage is

$$e = ir$$

where i is the current and r is the gage resistance. But the current is determined by the battery voltage, E, the gage resistance and the ballast resistance, R, by the relation,

$$i = \frac{E}{R + r}$$

* Baldwin Southwark SR-4 Strain Gauges.

Hence the voltage across the gage is

$$e = \frac{Er}{R + r}$$

Now as the gage is strained and changes resistance, the change in e per unit change of r is

$$e' = \frac{de}{dr} = \frac{ER}{(R + r)^2} = \frac{iR}{R + r}$$

This then is the signal voltage that can be obtained by a unit change in gage resistance. The DC voltage, e, is blocked by a condenser and the change in voltage Δ e is amplified and recorded. In practice, the maximum sensitivity that can be obtained is only slightly less than one millivolt per milliampere of current per ohm change of the gage. Thus if the gage can stand a current of 50 ma, a signal of roughly 0.050 volts can be obtained from a one ohm change. When a single gage is used with the sensitivity as given in paragraph 1, a signal voltage of about 0.080 volts can be obtained by an equivalent stress of 30,000 lbs. per square inch in steel.

5. The sensitivity is most easily adjusted by varying the ballast resistance R and consequently the current. If two gage elements are used in series as a single gage, then the sensitivity could be doubled provided the ratio of R/r and the current could be kept the same.

6. Calibration of the circuit to determine the sensitivity is done by shorting out a known resistance which is connected in series with the gage.

Amplifiers

7. For the measurement of most transient strains a DC amplifier with a long time constant isthe most satisfactory. Three such amplifiers are available in the portable laboratory trailer for use with the cathode ray oscillograph. A 5 megohm input resistor is usually used together with a blocking condenser of about 2 micro-farads. This gives a time constant of 10 seconds which is quite satisfactory for records of less than one second duration. These amplifiers will give full scale deflection to the cathode ray beam with an input voltage of about 0.1 volt.

Oscillograph Camera

8. The oscillograph camera consists of a 19" rotating drum with a spiralling mechanism which translates the drum axially 1/2" per revolution. It is arranged to photograph the screen of three-beam cathode ray tube, through a suitable lens system. The film width is four inches. Film speeds from about 60 to 500 inches per second can be obtained. Triggering of the beam deflecting circuits and spiralling clutch is accomplished by means of a solenoid, operated from the firing position. When the drum has spiraled the width of the drum it operates a switch which releases the spiraling clutch and again deflects the beams off the screen.