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STATISTICAL ANALYSIS OF SABOT PETAL
IMPACT DATA FOR M392 TYPE PROJECTILES

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December 1982



US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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The petal impact locations for each round are used to calculate their centroid and their relative locations with respect to it. These quantities are then statistically analyzed, revealing a strong dependence on the gun barrel motion. The angular distribution of the centroids for the two data samples exhibit the same pattern basically but are angularly displaced by about ten degrees. The distributions of the petal impacts relative to their centroid show distinct groupings at discrete values for both the angular orientation and the radial displacements. Such an energetic preference is possible if, and only if, the vibrating tube acts as a tuning device for the angular motion of the segmented ring formed by the three sabot petals.

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TABLE OF CONTENTS

	Page
LIST OF ILLUSTRATIONS.	5
LIST OF TABLES	7
I. INTRODUCTION	9
II. DATA ANALYSIS.	10
A. <u>Distribution Of Centers Of Sabot Petal Impacts</u>	13
B. <u>Angular Distribution Of Sabot Petal Impacts.</u>	16
C.. <u>Displacement Distribution Of Sabot Petal Impacts</u>	19
III. CONCLUDING REMARKS	23
REFERENCES	24
DISTRIBUTION LIST.	25

LIST OF ILLUSTRATIONS

Figure	Page
1. 105mm M392A2 APDS Subcaliber Kinetic Energy Projectile.	9
2. Schematic Of Setup Of Range Instrumentation	9
3. Geometry Of Sabot Petal Impacts	11
4. Centers Of Sabot Petal Impacts On Witness Board.	13
5. Angular Distribution Of Sabot Petal Impact Centers With Respect To Sample Average; Total Population	14
6. Angular Distribution Of Sabot Petal Impact Centers With Respect To Sample Average For Population M392A2 Modified.	15
7. Angular Distribution Of Sabot Petal Impact Centers With Respect To Sample Average For Population M392A2	15
8. Angular Distribution Of Sabot Petal Impact Centers With Respect To Sample Average For Population M392A2, Excluding Round #44.	16
9. Angular Distribution Of Sabot Petal Impacts Obtained From A Sample Of 51 Observations	17
10. Angular Distribution Of Sabot Petal Impacts Obtained From A Sample Of 21 Observations From Population M392A2 Modified	17
11. Angular Distribution Of Sabot Petal Impacts Obtained From A Sample Of 30 Observations From Population M392A2.	18
12. Angular Distribution Of Sabot Petal Impacts After Alignment Of The Samples From The Two M392A2 Populations	19
13. Schematic Of Angular Distribution Of Petal Impacts.	20
14. Dot Diagram Showing Mean Radial Displacement Of Sabot Petal Impacts	20
15. Observed Modes Of Rotation For Sabot Petal Ring	21

LIST OF TABLES

Table	Page
1. IMPACT LOCATIONS OF SABOT PETALS FOR M392A2 PROJECTILES EQUIPPED WITH BASE PLUG.	10
2. IMPACT LOCATIONS OF SABOT PETALS FOR M392A2 PROJECTILES	11
3. CENTERS OF PETAL IMPACTS AND PETAL IMPACT LOCATIONS WITH RESPECT TO THEIR CENTER	12
4. DEPARTURE ANGLE OF SABOT PETALS FROM MUZZLE	22

I. INTRODUCTION

In fall of 1977 firing tests were conducted to determine the interior ballistic causes for the adverse free flight performance and the effects of changes in the projectile assembly on the launch performance of the 105mm M392A2 subcaliber kinetic energy round^{1,2}. Figure 1 shows the projectile assembly with and without a base plug. The instrumentation assembled for this investigation and the experimental arrangement are depicted in Figure 2.

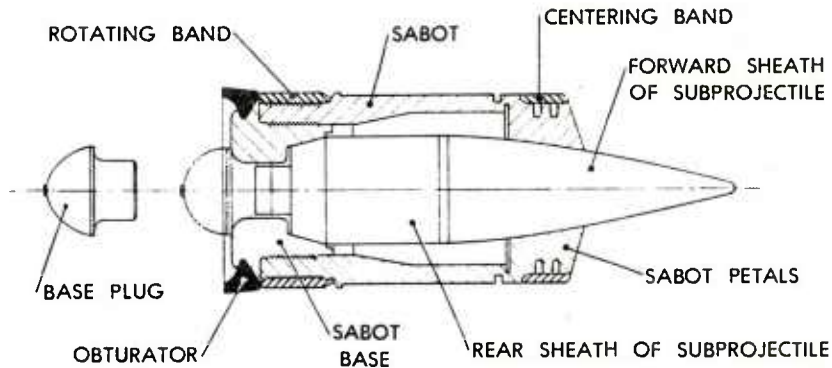


Figure 1. 105 mm M392A2 APDS Subcaliber Kinetic Energy Projectile

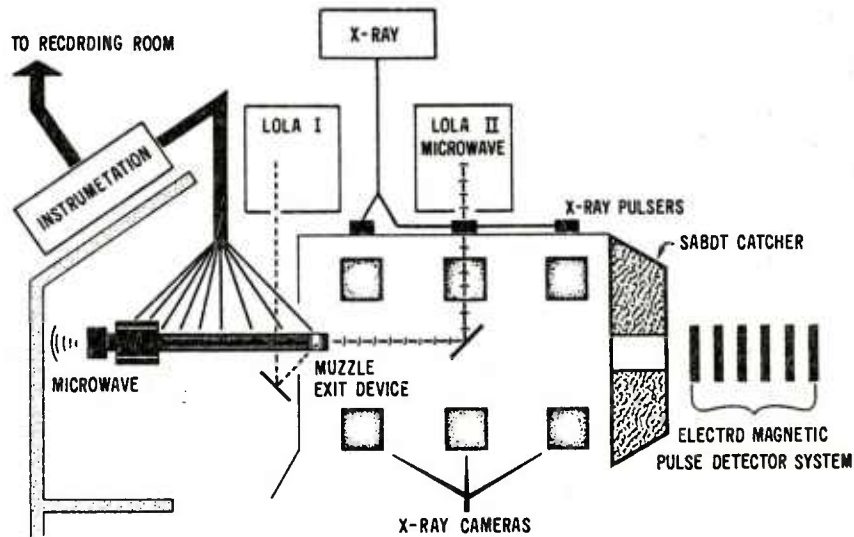


Figure 2. Schematic of Setup of Range Instrumentation

¹R.K. Loder, J.O. Pilcher, "Nondestructive Test Method To Establish The Performance Of Projectile Gun System," *Proceedings of the 26-th Defense Conference On Nondestructive Testing*, 15-17 November 1977, Seattle, WA.

²D.A. Ross, R.K. Loder, J.O. Pilcher, "In-Bore Motion of the M392A2 Projectile," *Proceedings of the DEA-G-1060 Ballistic Research and Development Meeting*, 25-28 April 1978, Dahlgren, VA.

Range safety and protection of instrumentation required that the sabot petals of the M392A2 projectiles be prevented from flying downrange. Therefore, a sabot catcher was erected eight meters from the muzzle. It allowed the undisturbed passage of the subprojectile and the sabot pot but retained the sabot petals. Five centimeter thick steel armor plates welded together formed the back and side walls of the structure, whereas 3.2 mm thick aluminum panels mounted to a steel frame were used for the front wall to permit penetration of the sabot petals into the interior of the structure. The structure itself was filled with sand for slowing down and arresting the petals. A steel tube with an interior diameter of 45 cm and with its centerline aligned with the firing line was inserted into the sabot catcher to allow unobstructed passage of the projectile.

Using the firing line as the center, the impact positions of the sabot petals on the front wall were recorded. Tables 1 and 2 contain the petal

TABLE 1. IMPACT LOCATIONS OF SABOT PETALS FOR M392A2 PROJECTILES EQUIPPED WITH BASE PLUG

Rd #	FIRING DATES				IMPACT LOCATIONS OF PETALS (cm)					
	M	D	HOUR	S	X #1	Y	X #2	Y	X #3	Y
23	11	4	11.50	2	-63.6	11.4	11.4	64.8	68.4	-69.6
25	11	4	14.15	3	-48.0	-48.0	.0	45.0	40.2	-40.2
38	11	16	12.15	2	-18.0	-24.0	-4.8	32.4	30.0	-26.4
40	11	16	14.15	3	-55.8	-52.8	-18.0	61.8	27.6	-16.8
41	12	6	13.35	1	-28.2	18.0	40.2	40.2	33.0	-12.0
42	12	7	09.55	1	-21.6	6.0	28.8	51.6	51.6	8.4
43	12	7	11.45	2	-40.2	-40.2	-25.8	25.8	20.4	-20.4

impact locations for the M392A2 projectiles fired with and without the base plug, respectively. The first column gives the round identification number, the next four columns give the month, day, hour and daily sequence of the shot, and the remaining columns give the horizontal and vertical components of the petal impact locations. Accuracy of the data is within ± 1.5 cm.

II. DATA ANALYSIS

From these data, one can calculate the center of petal impacts for each round and the impact locations of the petals with respect to their center (Table 3). Also shown are the angular positions of the individual centers of petal impacts with respect to the average of the total sample as well as the averages of the subsamples and the transverse velocity and spin of the petals at the muzzle exit. The geometric parameters referred to in this table are depicted in Figure 3.

TABLE 2. IMPACT LOCATIONS OF SABOT PETALS FOR M392A2 PROJECTILES

Rd #	FIRING DATES				IMPACT LOCATIONS OF PETALS (cm)					
	M	D	HOUR	S	X #1	Y	X #2	Y	X #3	Y
26	11	11	11.25	1	-58.8	13.2	24.0	39.6	.0	-39.6
27	11	11	15.20	2	-27.0	-16.8	-7.8	30.0	27.0	-16.2
28	11	14	11.20	1	-33.0	14.8	8.4	32.4	22.8	-28.8
29	11	14	14.00	2	-31.8	2.4	7.2	31.8	22.2	-28.2
30	11	14	15.20	3	-21.0	21.0	24.0	24.0	-2.4	-38.4
33	11	15	10.15	1	-31.8	-3.6	8.4	34.2	24.0	-24.0
34	11	15	11.40	2	-30.0	-9.6	.0	33.6	25.2	-25.2
36	11	15	13.35	3	-22.2	22.2	22.2	1.2	-9.6	-24.0
37	11	16	09.45	1	-6.0	31.2	36.0	9.6	-4.2	-30.0
44*	12	07	14.40	3	-3.0	-25.8	4.2	36.6	75.6	-24.0

*fired with an "improved" obturator

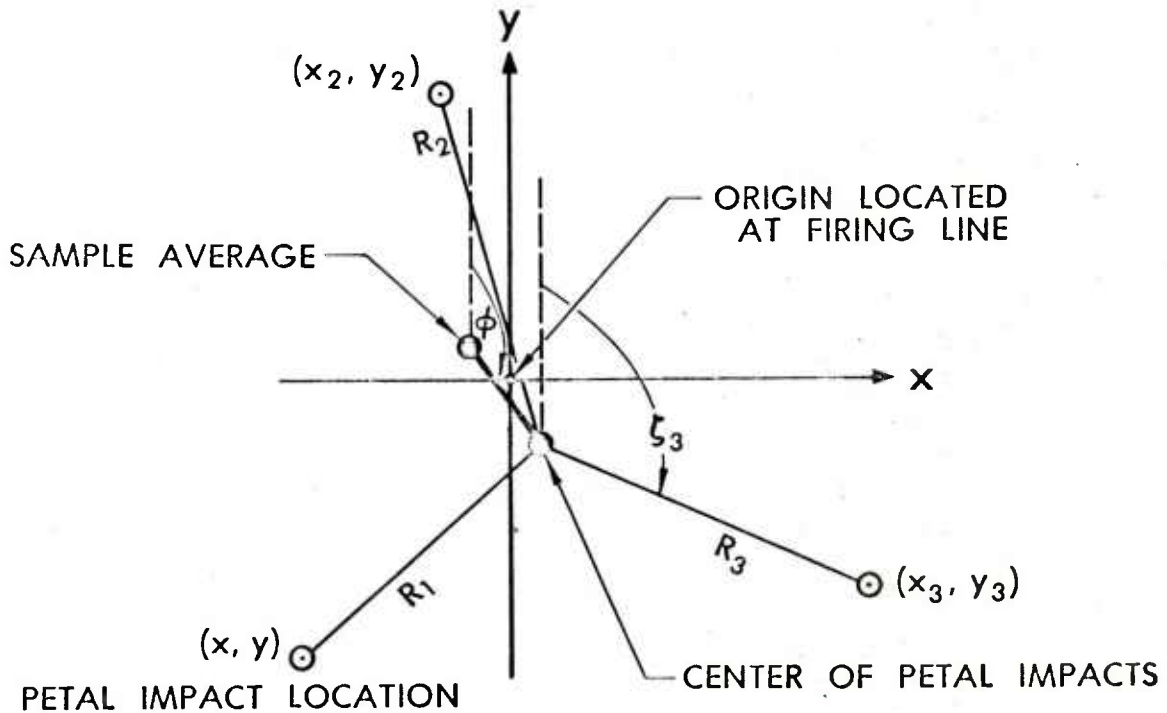


Figure 3. Geometry of Sabot Petal Impacts

TABLE 3. CENTERS OF PETAL IMPACTS AND PETAL IMPACT LOCATIONS WITH RESPECT TO THEIR CENTER

Round #	Centers of Petal Impacts				Impact Locations Of Sabot Petals						Sabot Ring Velocity 4)		
	x [cm]	y [cm]	ϕ [°] 1)	ψ [°] 2)	R [cm]	ϕ [°] 3)	R [cm]	ϕ [°] 3)	R [cm]	ϕ [°] 2)	R [cm]	V_t [m/sec]	S [rev/sec]
26	-11.6	4.4	286	286	48.0	281	50.0	45	45.5	165	47.9	81.2	421
27	-2.6	-1.0	247	208	29.1	237	31.4	351	53.3	117	31.3	51.1	265
28	-.6	.4	241	159	32.7	262	34.0	15	36.8	141	34.5	57.0	295
29	-.8	2.0	301	40	31.0	271	30.9	15	38.0	143	33.3	54.7	284
30	.2	2.2	322	62	28.3	312	32.3	48	40.7	184	33.8	55.6	288
33	.2	2.2	322	62	32.5	260	33.0	14	35.4	138	33.7	55.4	287
34	-1.6	-.4	250	189	29.9	252	34.0	3	36.5	133	33.5	55.1	286
36	-3.2	-.2	68	77	29.4	320	25.4	87	24.6	195	26.5	42.5	220
37	8.6	3.6	259	230	31.2	332	28.0	78	36.0	201	31.7	52.3	271
44 5)	25.6	-5.9	105		34.8	235	47.6	333	54.8	114	45.8	82.9	430
23	5.4	2.2	70	71	69.6	278	62.9	6	95.5	139	76.0	132.2	685
25	-2.6	-14.2	195	195	56.6	233	59.3	3	50.1	121	55.3	90.6	490
38	2.4	-6.0	171	171	27.2	229	39.1	349	34.3	127	33.5	55.2	286
40	-15.4	-2.6	259	258	64.4	219	64.5	358	45.3	108	58.1	99.7	517
41	15.0	15.4	43	43	43.3	273	35.4	46	32.8	147	37.1	61.8	320
42	19.6	22.4	40	40	44.3	248	30.6	18	34.9	114	36.6	60.6	314
43	-15.2	-11.6	233	233	38.0	221	38.9	344	36.7	104	37.8	63.0	327

- 1) Angle of center of petal impacts with respect to sample average; clockwise, starting at the twelve o'clock position
- 2) Angle of center of petal impacts with respect to subsample average; clockwise, starting at the twelve o'clock position
- 3) Angle of petal impact location with respect to its center; clockwise, starting at the twelve o'clock position
- 4) A projectile velocity of 1450 m/sec at muzzle exit was assumed for all projectiles
- 5) This round was equipped with an "improved obturator"

A. Distribution of Centers of Sabot Petal Impacts

Figure 4 shows graphically the centers of petal impacts for all rounds for which the impacts were recorded. The averages for the subsamples, M392A2 unmodified and modified with the base plug, coincide with the sample average. Though included in the first population, round #44 actually belongs to a third population since the standard obturator was replaced by a wider one, thus changing the very early projectile in-bore motion. Excluding this round from the first population, one observes that all rounds belonging to this population are compactly grouped about their average of petal impacts. All errors indicated correspond to one sample standard deviation.

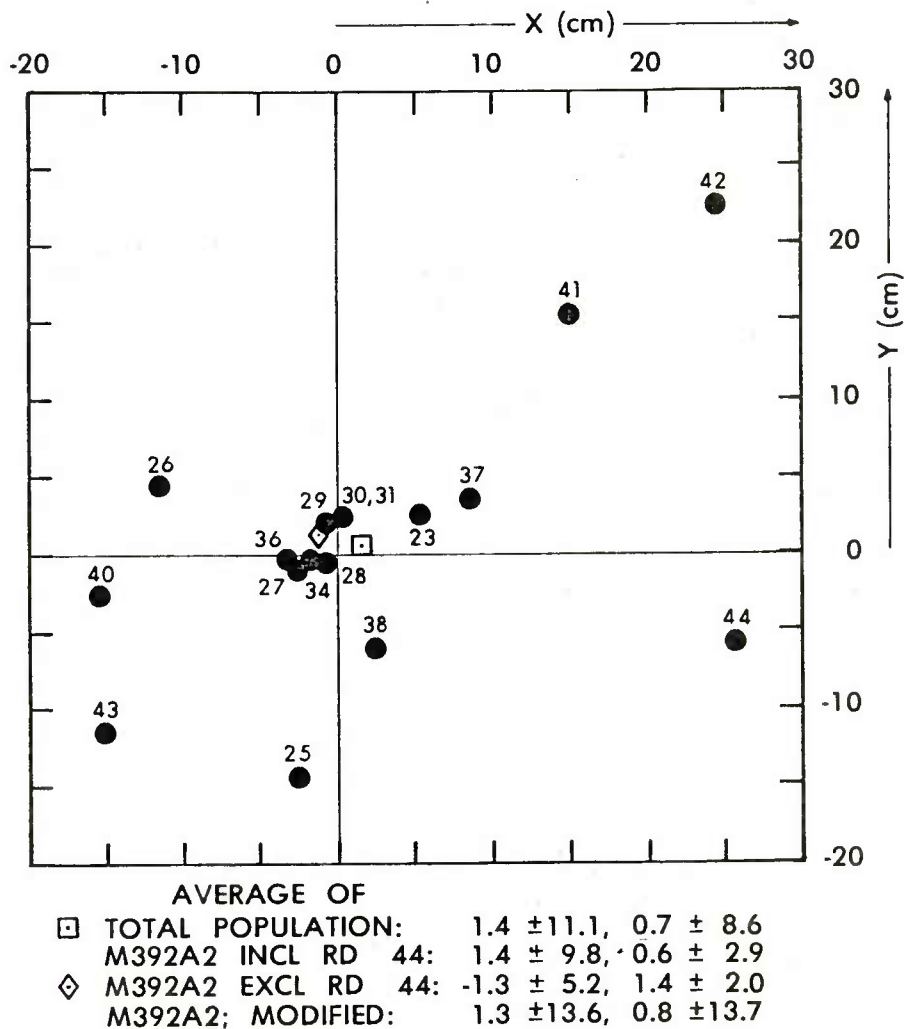


Figure 4. Centers Of Sabot Petal Impacts On Witness Board

The angular distribution of the individual centers of sabot petal impacts with respect to the total sample average (Figure 5) indicates that the population distribution is nonrandom and has preferred directions. This

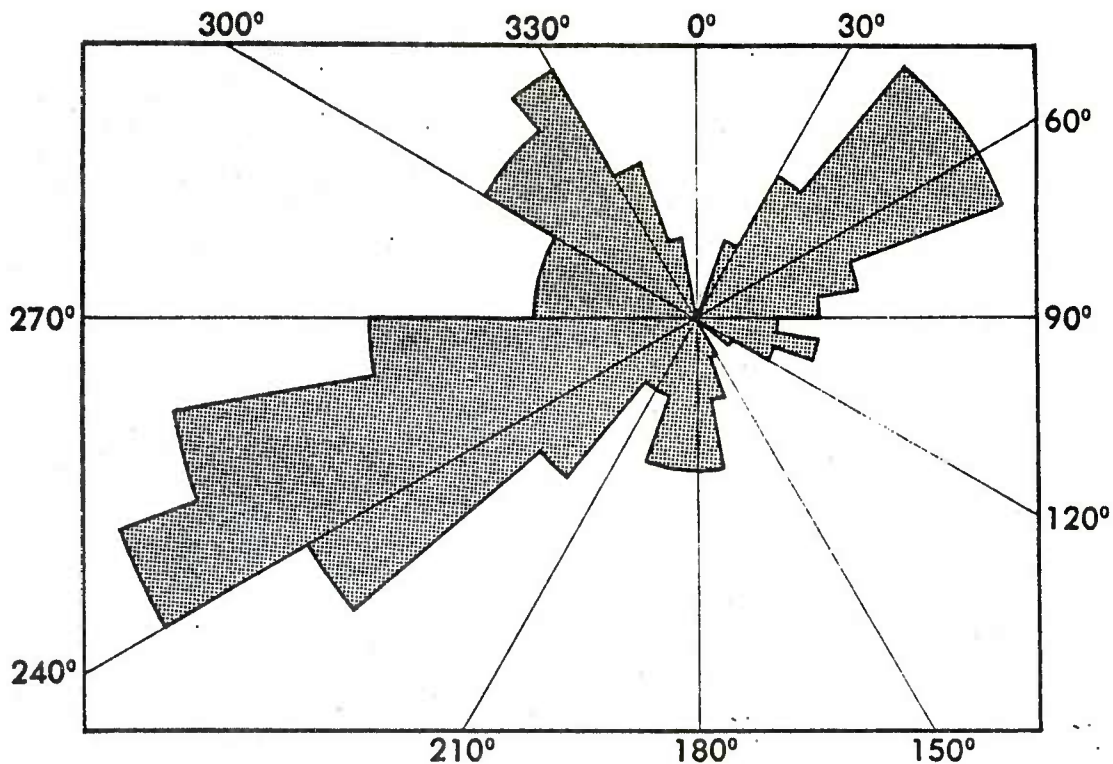


Figure 5. Angular Distribution Of Sabot Petal Impact Centers With Respect To Sample Average; Total Population

frequency diagram and all subsequent ones are generated by dividing the parameter axis into intervals of appropriate size and constructing over the i -th interval an area which is proportionally weighted to the number of observations in that interval and in its neighboring intervals. In the above diagram, for instance, an observation which fell in the i -th interval contributed half of its score to the i -th interval and one fourth to the $(i-1)$ -th and $(i+1)$ -th interval, respectively. A nonrandom angular distribution for the centers of the sabot petal impacts was expected, because the muzzle motion at the time of projectile exit from the gun generally is nonrandom and the wear of the tube used for this experiment suggested two preferential transverse alignments of projectile axis during in-bore travel. It is intended to investigate the correlation between transverse muzzle velocity, alignment of projectile axis, and location of sabot petal impact center in more detail after all tube acceleration and strain data have been analyzed.

The angular distribution of the centers combines the observations from at least two populations. Separating the main contributions, one observes that the sample from the population M392A2 modified (Figure 6) exhibits three main angular directions at 51° and $215.5 \pm 31.5^\circ$. The sample from the population M392A2 unmodified includes round #44 which actually belongs to another population and unduly distorts the angular distribution (Figure 7). Excluding round #44 from the sample size (Figure 8), one obtains a pattern similar to that observed for the modified projectiles.

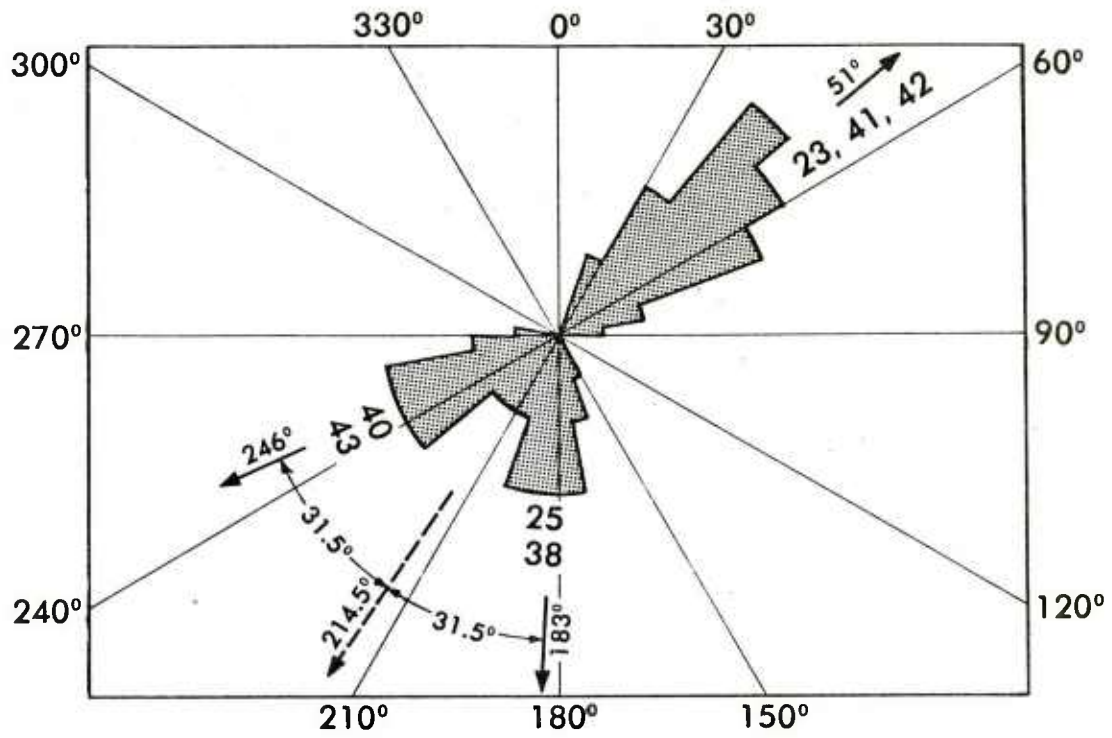


Figure 6. Angular Distribution Of Sabot Petal Impact Centers With Respect To Sample Average For Population M392A2 Modified

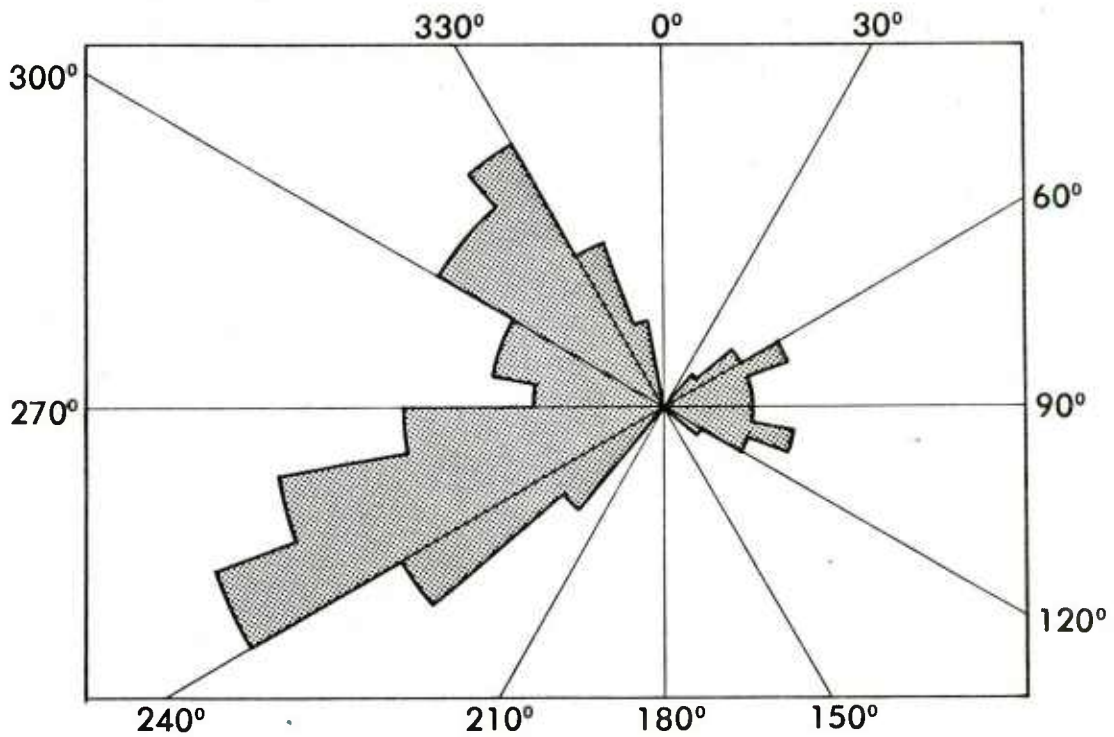


Figure 7. Angular Distribution Of Sabot Petal Impact Centers With Respect To Sample Average For Population M392A2

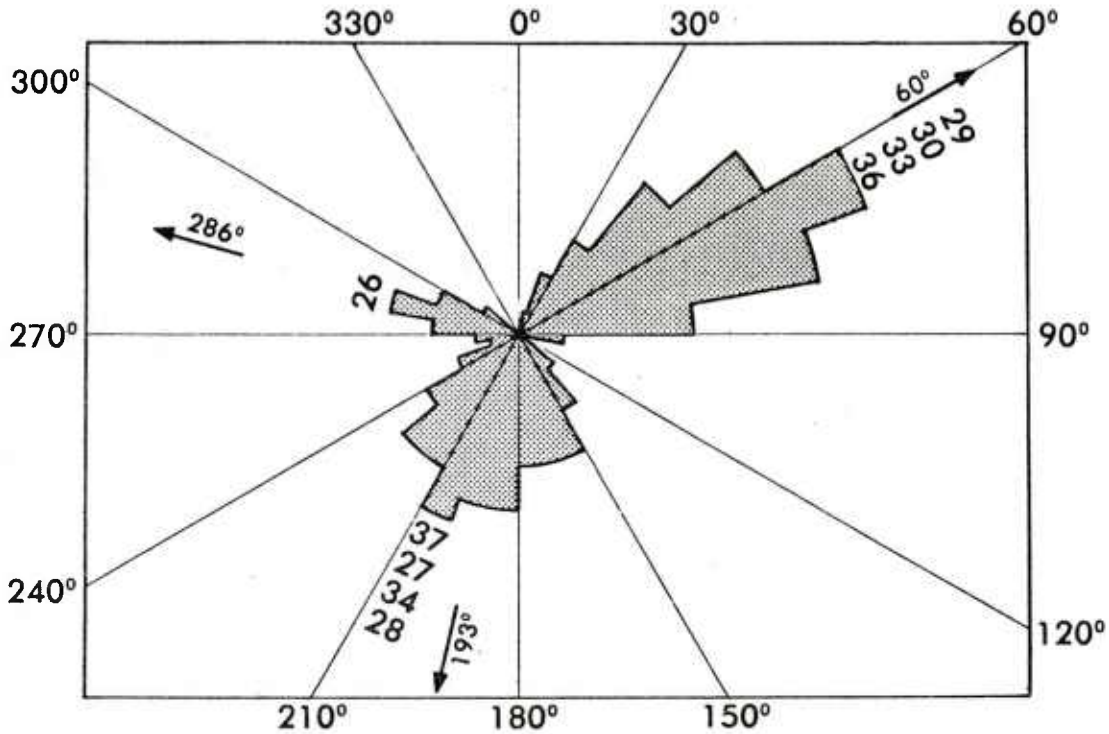


Figure 8. Angular Distribution Of Sabot Petal Impact Centers With Respect To Its Sample Average For Population M392A2, Excluding Round #44

Though the angular distributions are based on small sample sizes, the coincidence of two populations having the same distribution pattern strongly indicates that the conglomeration of petal impact centers at the distinct angles is real and may be deterministically relatable to the projectile launch mechanism.

B. Angular Distribution of Sabot Petal Impacts

Table 3 also contains the impact locations of the sabot petals with respect to this center in polar coordinates. The frequency diagram for the azimuths of these vectors (Figure 9) shows that the angular distribution of the sabot petal impacts is not uniform as expected, when plotted modulo 120 degrees. Apparently, the impacts are aggregated into groups. Statistical analysis of the distribution indicates four groupings. Since the observations pertain to basically two distinct populations of projectiles, it is advisable to part and analyze them separately. The population M392A2 modified (Figure 10) is grouped about three directions: $\phi_I = 8.7^\circ$, $\phi_{II} = 35.2^\circ$, and $\phi_{IV} = 108.7^\circ$. The angles of the second and third direction with respect to the first one are $\Delta\phi_{I,II} = 26.5^\circ$ and $\Delta\phi_{I,IV} = 100^\circ$, respectively. The frequency diagram shows the directions of the groupings with their one sample standard deviation and identifies the rounds belonging to the groups. The sample from the population M392A2 unmodified (Figure 11) is grouped about the four directions: $\phi_I = 17.2^\circ$, $\phi_{II} = 43.7^\circ$, $\phi_{III} = 75^\circ$, and $\phi_{IV} = 117.5^\circ$. The angles between the

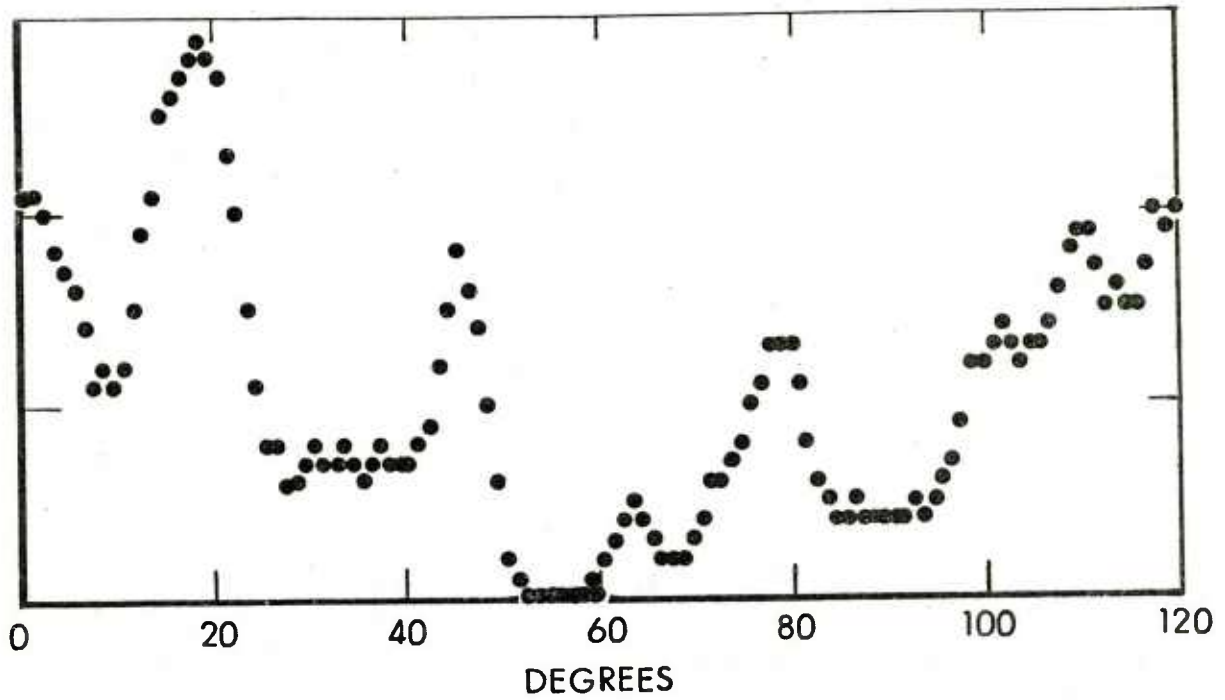


Figure 9. Angular Distribution Of Sabot Petal Impacts Obtained From A Sample Of 51 Observations

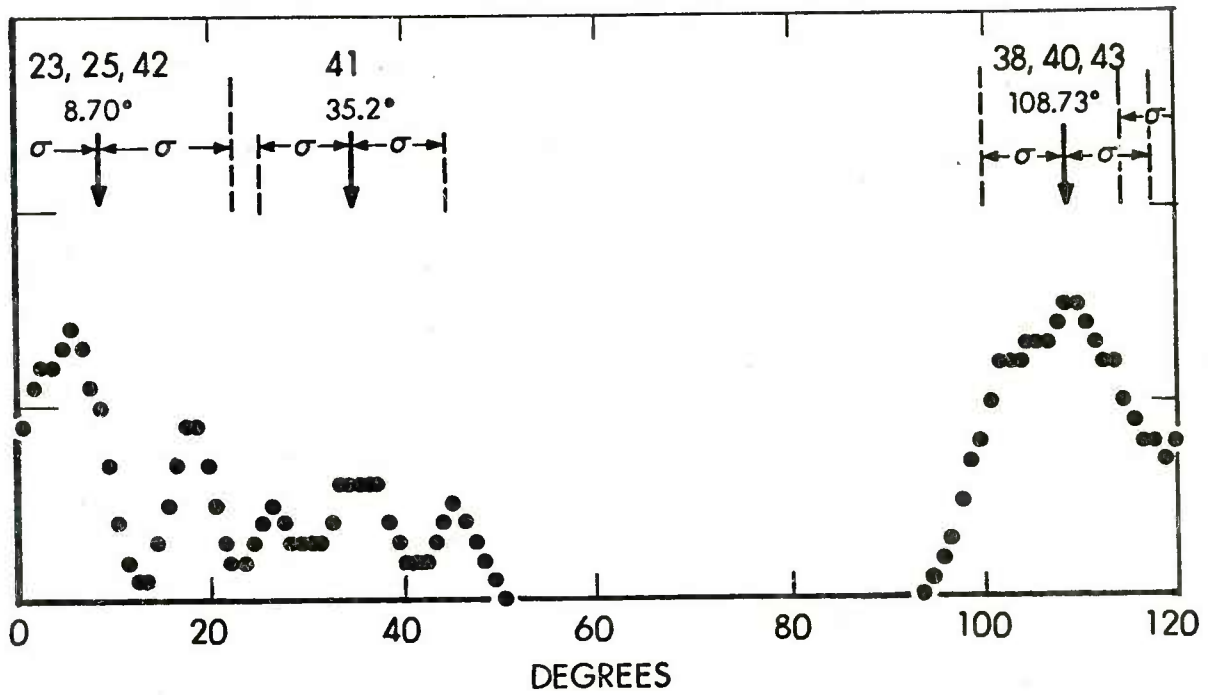


Figure 10. Angular Distribution Of Sabot Petal Impacts Obtained From A Sample Of 21 Observations From Population M392A2 Modified

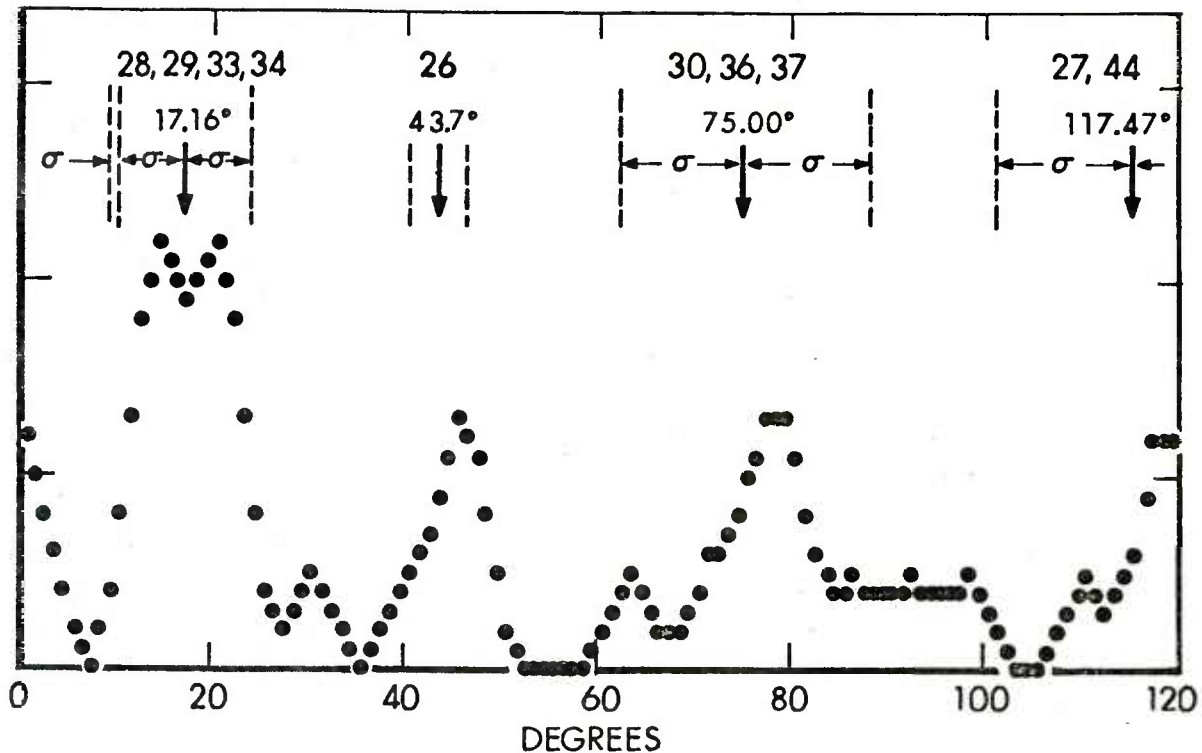


Figure 11. Angular Distribution Of Sabot Petal Impacts Obtained From A Sample Of 30 Observations From Population M392A2

directions of the groupings with respect to the first one are $\Delta\phi_{I,II} = 26.5^\circ$, $\Delta\phi_{I,IV} = 57.8^\circ$ and $\Delta\phi_{I,IV} = 100.3^\circ$, respectively. These angular displacements are practically identical to those obtained for the first sample. By rotating the angular sample distribution for the population M392A2 modified by 8.5° , the angularly preferred directions can be brought to coincide with those obtained for the population M392A2 unmodified (Figure 12), thus emphasizing the groupings of the sabot petal impacts. The angular directions for the groups III and II exhibit themselves as mirror images of the directions for the groupings I and IV, respectively, as shown schematically in Figure 13.

The grouping of the sabot petal impact locations about preferential directions cannot be considered an accidental artifact introduced by the small sample size, since it occurs for both sample distributions and has also been observed in a firing test conducted at Yuma Proving Ground, July 1981³. Therefore, one must find a physically plausible explanation for this unexpected angular bias. Theoretical models of the in-bore motion of the sabot petals⁴,

³R.B. Murray, Ballistic Research Laboratory, (private communication)

⁴M.T. Soifer, "Analysis Of The In-Bore Motion And Loadings Of The Sabot Petals Of The M392 Projectiles," Contract Report by S&D Dynamics, Inc., Huntington, N.Y. (March 1978), (Unpublished).

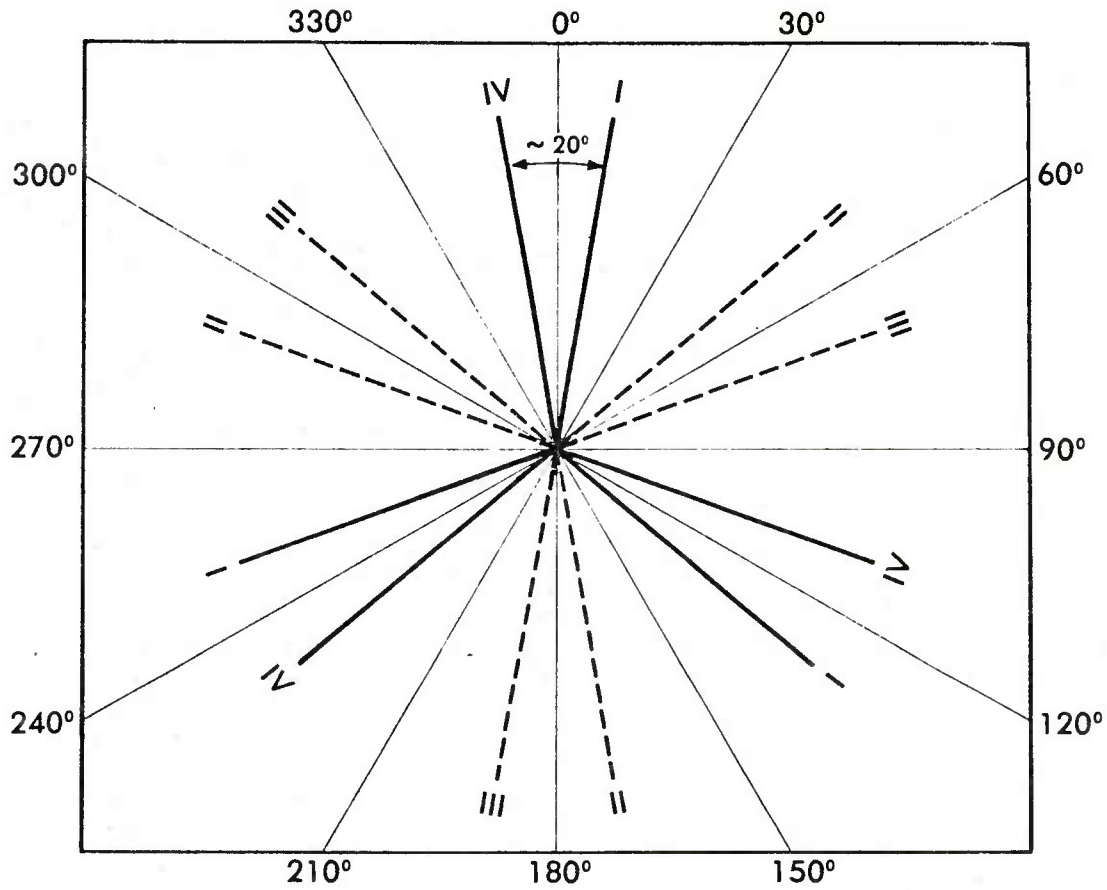


Figure 13. Schematic Of Angular Distribution Of Petal Impacts

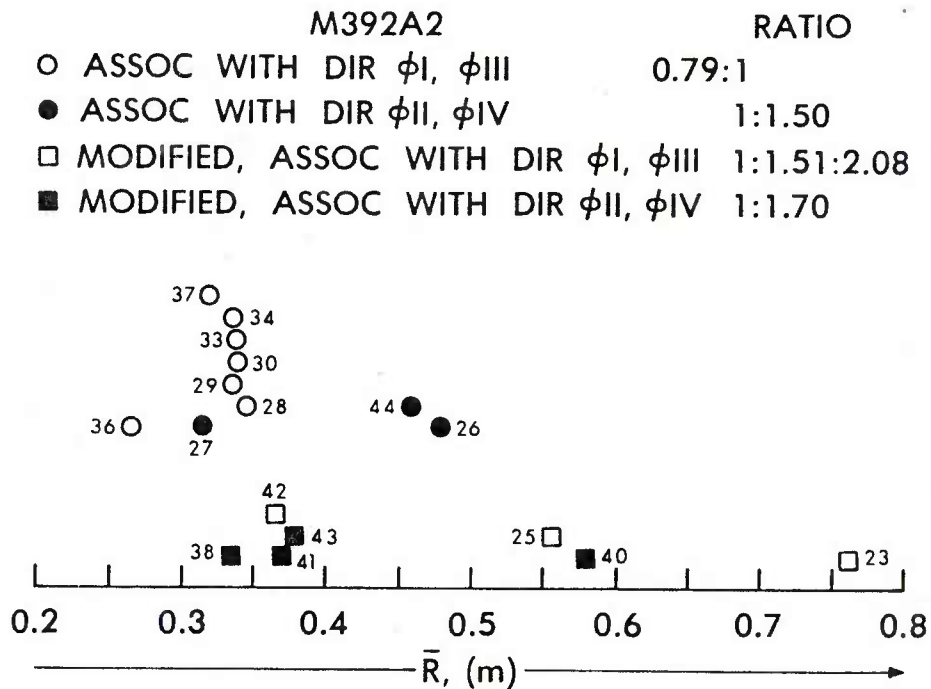


Figure 14. Dot Diagram Showing Mean Radial Displacement Of Sabot Petal Impacts

the projectile M392A2 modified are about nine percent larger than those for the M392A2. A group structure is readily recognizable from the data. The sample from the population M392A2, excluding round #36, shows two distinct groupings of distances, whereas the sample from the population M392A2 modified exhibits three. The groups are spaced approximately 1 : 3/2 : 2 apart.

The transverse velocity of the petals at muzzle exit, v_t , is directly proportional to the mean radial displacement of the sabot petal impacts with respect to their center of impact \bar{R} ,

$$v_t = w \cdot r_{cg} = v_M \cdot (R^2 - r_{cg}^2)^{1/2} / L ,$$

where w is the angular velocity of the ring formed by the three petals, r_{cg} ($=30.7$ mm) is the original displacement of the center of gravity of a sabot petal with respect to the bore axis, v_M (≈ 1450 m/sec) is the velocity of the projectile at the time of its exit from the muzzle, and L (≈ 8 m) is the distance from the muzzle to the witness board. Table 3 also contains the transverse velocity and the spin of the sabot petal ring, assuming a uniform muzzle velocity of 1450 m/sec for all rounds. The relative error introduced by this approximation is of the order of one percent. The group spacing of 1:3/2: 2 is preserved. Interpretation of these spacing ratios in terms of angular velocity is straightforward. During the time period $\tau = 2\pi/w$ a sabot petal belonging to the first group makes one complete revolution (Figure 15a), a

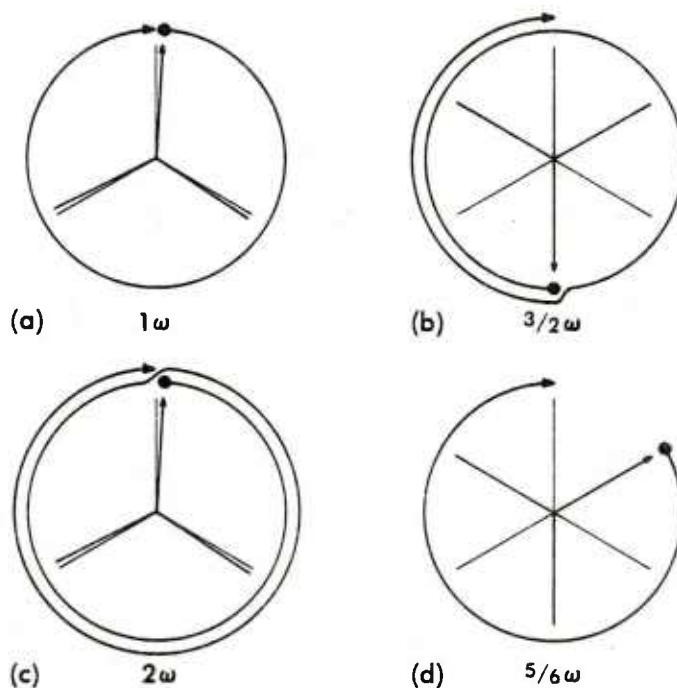


Figure 15. Observed Modes Of Rotation For Sabot Petal Ring

petal belonging to the second group makes one and one half revolutions (Figure 15b), and a sabot petal belonging to the third group makes two complete revolutions (Figure 15c). This rotational velocity pattern explains the observed grouping in the angular distribution of the petal impacts. As indicated before, round #36 does not fall into the observed angular velocity bands. Either the sabot petals were still in the process of spinning up to the stable angular velocity band of "1w" or belong to a lower stable band as indicated in Figure 14d.

Another way to look at the impact data is to transform the radial displacements into sabot petal departure angles at the muzzle (Table 4).

TABLE 4. DEPARTURE ANGLE OF SABOT PETALS FROM MUZZLE

PROJECTILE TYPE	ANGULAR VELOCITY BAND	MEASURED DEPARTURE ANGLES	
		ANG. DISTR. GROUP I/III	ANG. DISTR. GROUP II/IV
M392A2 (mean departure angle: 2.55°)	5/6 w	1.67°	-----
	1 w	2.17°	2.23°
	3/2 w	-----	3.94°
	2 w	-----	-----
M392A2 mod. (mean departure angle: 2.70°)	5/6 w*	-----	-----
	1 w*	2.40°	2.02°
	3/2 w*	3.74°	3.14°
	2 w*	5.23°	-----

The averages of the departure angles for the samples from the two populations are listed also. Schmidt et al.⁵ obtained for a one third scale model of the 105 mm, M68 tank gun and the M392A2 kinetic energy projectile, a value of 5.88° which is about six percent lower than the theoretical value of 6.26° expected for petals rotating with the rifling, but 110 percent higher than the cited value of 2.8° obtained from a 1977 TECOM test firing of the actual M392A2 projectiles⁶. The mean departure angle in this experiment is nine percent lower than the TECOM value.

⁵E.M. Schmidt, B.P. Burns, G. Samos, "Replica Modeling Of The Launch And Flight Dynamics Of Projectiles," Technical Report ARBRL-TR-02104, USAARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, September 1978.

⁶E. Kelly, "Firing Record: Cartridge, 105mm, APDS-T, M392A2," FR-P-82598, Test and Evaluation Command, Aberdeen Proving Ground, MD, June 1977.

III. CONCLUDING REMARKS

Analysis of the sabot petal impact data indicates that the 105 mm M68 tank gun - M392A2 projectile system is characterized by a synergism of projectile in-bore motion and tube motion which (i) acts as a tuning mechanism for the angular in-bore motion of the sabot petals, forcing them into discrete angular velocity and orientation bands compatible with the tube vibration and (ii), at the time of projectile exit from the muzzle, imparts a transverse velocity component on the sabot petals such that the centers of petal impacts of the individual rounds are distributed about a few preferred angular orientations.

Attempts are under way to correlate these observations with other projectile and gun dynamic parameters obtained from the same firing experiment and to use them as a means for assessing muzzle motion and subprojectile spin at shot exit qualitatively as well as quantitatively.

The angular velocity and orientation tuning of the sabot petals should not be considered an oddity, peculiar only to the M392A2 type of projectiles. Theoretically, this effect could occur for all projectile configurations which have angularly segmented sabots and a slipping ring for only partial transmission of the rifling torque to the subprojectile. Therefore, one should attempt to measure the launch parameters of the sabot segments for this type of projectile whenever possible and periodically conduct a statistical analysis of the accumulated data. The use of a witness board for recording sabot impact is probably the most cost effective measurement setup available.

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