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TECHNICAL NOTE NO. 1653

RETARDATION AND CONDITION OF SHOT PELLETS IN FREE FLIGHT

by

W. F. Donovan

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U. S. ARMY MATERIEL COMMAND
BALLISTIC RESEARCH LABORATORIES
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B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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Exterior Ballistics Laboratory

RDT&E Project No. 1P014501A33D

A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

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ABSTRACT

In any estimate of the trajectories of shot fired from a shotgun, the drag of the system of pellets might be expected to vary with the degree of damage incurred by the pellets and with the Mach and Reynolds Numbers. Results of experiments are presented for representative shot fired from a riot gun for five loading conditions. Pellet distributions, damage incidence, and aerodynamic retardations are determined from spark shadowgraphic traces. Pellets with severe launch damage indicate higher drag than corresponding spheres launched individually.

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LIST OF SYMBOLS

Symbol	Description	Unit
c	sonic velocity in undisturbed air	ft/sec
d	diameter of pellet	ft
dV/dZ	velocity gradient along flight path	sec^{-1}
ℓ	characteristic length for Reynolds Number	ft
m	mass of pellet	lb_m
C_D	drag coefficient $\frac{2\,m\,\alpha}{\rho S}$	1
M	Mach Number V/c	1
R_e	Reynolds Number $\frac{\rho\,\ell\,V}{\mu}$	1
S	frontal cross sectional area $\pi/4\ d^2$	ft^2
V	velocity with respect to undisturbed air	ft/sec
Z	distance along flight path	ft
α	retardation $\frac{dV/dZ}{V}$	ft^{-1}
μ	absolute viscosity of air	lb_m/ft sec
ρ	density of air	lb_m/ft^3

I. INTRODUCTION

In the evaluation of the trajectories of shot charges, it is usually assumed that the average trajectory can be computed as if it were the trajectory of a single sphere of the same size as an individual pellet. A dominant characteristic of a shot charge is that it is a conglomerate of pellets, at least in the early part of the trajectory. This experiment was undertaken to examine the implications of this assumption on the characteristic aerodynamics of the system of pellets. The actual behavior of individual pellets within the charge has often been conjectured, but several factors[1*] complicate the aerodynamic analysis. For example:

- The drag of a sphere is a complicated function of the Reynolds Number, $\frac{\rho \ell V}{\mu}$, and Mach Number, V/c, in the size and velocity ranges encountered.[2,3]
- Some of the individual pellets are damaged in launching and are no longer spherical.
- Many of the pellets are traveling in the disturbed air created by the passage of other pellets.

Recently, as an adjunct to another investigation, an attempt was made to obtain and analyze data on shot charges by utilizing the instrumentation of the free flight ranges at the Ballistic Research Laboratories (BRL). The results of this limited investigation are presented to aid in the understanding of the actual flight conditions of pellet groups.

II. BACKGROUND AND TESTING

The shotgun firing a pellet group has limited military application; and exterior ballistic testing of the shotgun load is usually restricted to pattern tests and muzzle velocity determination. Such testing does not require the instrumentation of the spark-shadowgraphic

Superscript numbers denote references which may be found on page 24.

ranges which is necessary in the investigation of the ballistic properties of shell. The larger spark range facility, the Transonic Range,[4] provides a 20 by 20 foot wind free test area and has been used by various groups doing small arms tests, including some shotgun surveys. In a recent test, a few shotgun rounds were fired within the instrumented path to see if a shadowgraph of the shot charge string could be obtained.* The shadowgraphs that resulted are shown in Figures 1, 2 and 3. The results were interesting but furnished no quantitative data for two reasons:

- the tiny photographic image was not sufficiently distinct to assess the condition of the pellets,
- the 20 foot inter-station spacing was too large to provide deceleration data for such a rapidly decelerating object.

The Aerodynamics Range[5] had never been considered for shotgun tests because its limited test area, about 1-foot square, would lead to impacts of the more erratic members of the shot string early in the trajectory and any attempt at pattern tests would be unsuccessful. The limited success in the Transonic Range prompted a review of the possibility of utilizing the smaller facility with emphasis on what it might do, rather than what it certainly could not do; i.e., contain the entire shot pattern. For example:

- The stations had triggered reliably on objects as small as 0.050 inch in diameter.
- The shadowgraphs had clearly shown small flats and other forms of damage on small projectiles.

**The Transonic Range stations were designed to operate with 57mm shell and larger; but with special adjustment have accommodated programs using 20mm projectiles. A single pellet could not be expected to trigger a station, but several pellets in close proximity offered the possibility of success.*

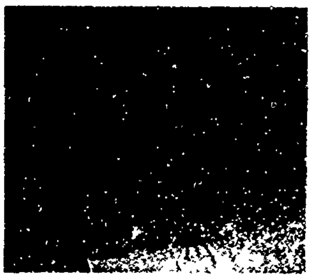


Figure 1 Round 6 Station 51 P
Transonic range plane of shadowgraph is horizontal

Figure 2 Round 2 Station 52 P
Transonic range plane of shadowgraph is horizontal and approximately 20 feet downstream of Figure 1

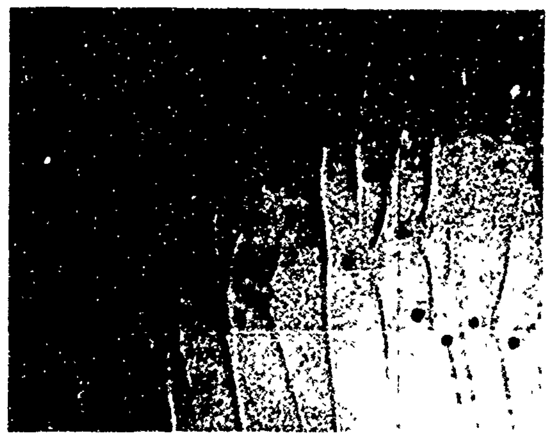


Figure 3 Round 6 Station 55 P
Transonic range plane of shadowgraph is horizontal and approximately 80 feet downstream of Figure 1

- The 5-foot station spacing was adequate to determine pellet deceleration if a sufficient number of stations was traversed.
- The instrumentation was armored adequately with regard to possible pellet impact and little damage would be expected.

Five of the charges used in contemporary pattern tests were selected and fired through the Aerodynamics Range instrumentation to establish feasibility.

The rounds were fired from a conventional weapon with an optional muzzle choke attachment. The gun was mounted in a Frankford rest. The charges contained 27 No. 4 Buckshot pellets and were fired at nominal muzzle velocities of 1100-1200 feet per second. A further description of the guns and charges is given in the Appendix.

III. EVALUATION OF PELLET DAMAGE AND PACK DISTRIBUTION

The photographic evidence, consisting of two orthogonal projections of the pellets at each range station, e.g., Figures 4 and 5, were examined and an attempt was made to identify each pellet image appearing on the first station with an image appearing on succeeding stations. In the case of leading or otherwise isolated pellets this could be done by inspection; in other cases, those images yielding data that could be connected to present a smooth individual trajectory were considered to represent an identifiable pellet. In this manner, 10, 25, 16, 27, and 24 of the 27 shot present in each of the five rounds were identified on two or more of the range timing stations. Identification was aided by the interposition of one or two purely photographic stations between each timing station.

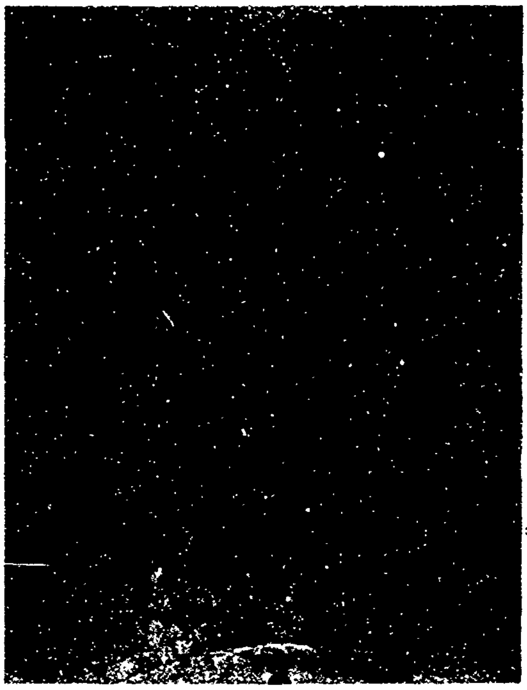


Figure 4

Station 2-V

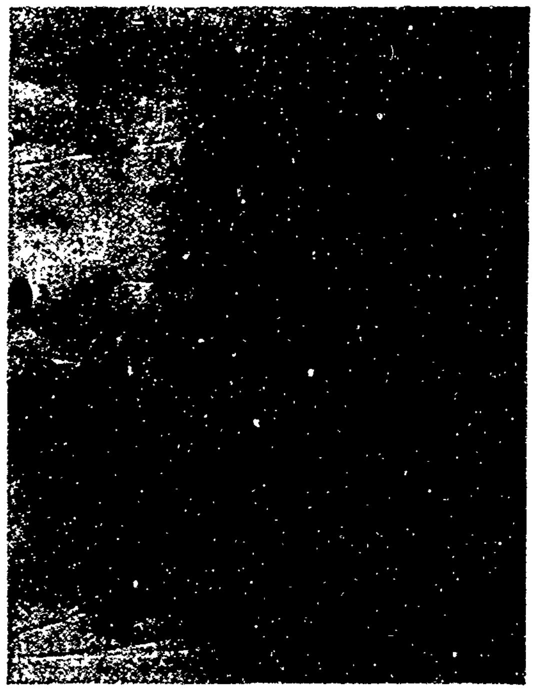


Figure 5

Station 5-V

Round 7019 Migration of pellets. At Station 2, the order is 1-2-3-7-5-4-6-8-10 ... At Station 5, the order is 2 (off plate), then 1-7-3-5 ...

Tracking and identification of the individual pellets permit an evaluation of the gross damage; however, a rational basis for the assigned damage assessment must be established. Each pellet was therefore examined for evidence of damage as indicated by its orthogonal projections on the station photographic plates. Usually, ten pairs of readable plates, with a 2.5 to 5-foot station spacing extending over a 40-foot trajectory, were available per round. Figure 6 illustrates one set of designated pellets for Round 7017. From these observations each pellet was graded as:

A = no damage or small flats

B = slight ovalness

C = large flats or barrel shape, and

D = gross deformation.

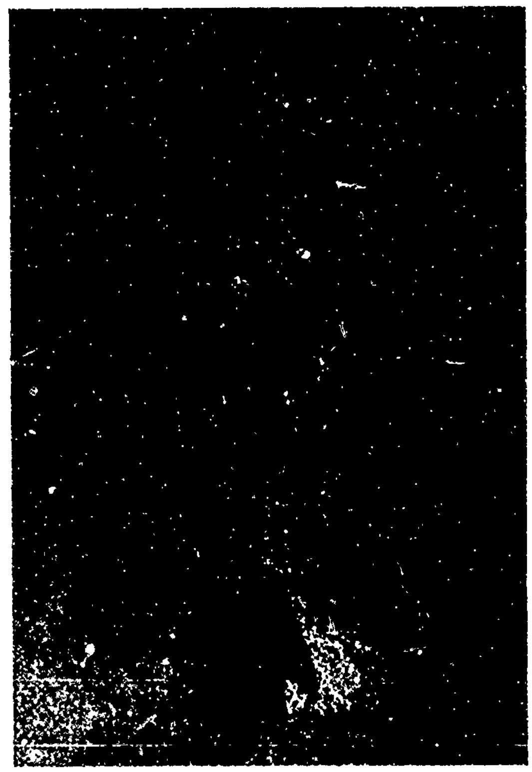


Figure 6

Round 7017 Station lV Loading SP 12 Damage Identification

Such a classification is admittedly subjective; a single set of two-view projections can fail to show small to medium sized flats which happen to lie in regions not exposed to the light sources, but since each pellet is probably turning slowly, the cumulative information from successive stations improves the resultant evaluation.

The pellet damage can be more severe than such examination would indicate. This possibility is most likely on pellets considered to have little or no damage; thus one might say that some pellets graded as "A" probably are of the "B" type, and that, to a lesser degree, there is a chance that some graded as "B" might be "C's".

The data on pellet condition are presented in Tables I and II. It was noted that the pellets passing out of the field of view early were not restricted to the grossly deformed classification but covered a

Table I. Average Retardation of Pellets

Round Number	Averages of Retardation of Pellets α (ft^{-1})									
	All Pellets	Pellet Condition				Pellets Passing 4 Stations	Pellet Condition			
		A	B	C	D		A	B	C	D
7012	.00415	.004214	.00399			.00413	.00398	.00443		
No. Pellets	7	5	2			3	2	1		
7014	.003578		.003578			.003319		.003319		
No. Pellets	25		25			13		13		
7015	.004273		.00388	.00404	.00484	.00391		.00388	.00396	
No. Pellets	9		2	4	3	3		2	1	
7018	.00403	.00376	.00414			.00363	.00368	.00355		
No. Pellets	25	7	18			8	5	3		
7019	.00384	.00385	.00385	.00351		.00377	.00364	.00384		
No. Pellets	23	8	14	1		14	5	9		
Grand Average	.00389	.00391	.00383	.00394	.00484	.00364	.00371	.00359	.00396	
No. Pellets	89	20	61	5	3	41	12	28	1	

Table II. Retardation of Individual Pellets

Rd. No.	Pellet No.	Velocity ft/sec.	α ft^{-1}	No. of timers		Condition
7012	1	1221	.00398	4	A-	round-in roughness
	2	1221	.00443	4	B	barrel 15/12 D_1/D_2
	3	1236	.00398	3	A-	round-slight squash 15/14
	4	1231	.00450	3	A-	round-slight squash 15/14
	5	1233	.00463	3	A	round-flying in wake
	6	1198	.00398	4	A	round-slight squash 15/14
	7	1255		2		
	8	1253		2		
	9	1232	.00355	3	B	oblong 14/12
	10	1249		2	A	round
7014	1	1265	.00387	3	B+	slight deformation
	2	1262	.00317	4	B+	
	3	1252	.00364	4	B+	
	4	1253	.00406	4	B+	
	5	1243	.00372	4	B+	
	6	1252	.00303	4	B+	
	7	1253	.00310	4	B+	
	8	1270	.00205	3	B+	
	9	1249	.00390	4	B+	
	10	1261	.00312	4	B+	
	11	1251	.00336	4	B+	
	12	1257	.00180	4	B+	
	13	1245	.00378	4	B+	
	14	1267	.00473	3	B+	
	15	1250	.00324	4	B+	
	16	1265	.00312	3	B+	
	17	1257	.00478	3	B+	
	18	1252	.00372	3	B+	
	19	1258	.00403	3	B+	
	20	1263	.00314	3	B+	
	21	1250	.00313	4	B+	
	22	1252	.00471	3	B+	
	23	1253	.00431	3	B+	
	24	1254	.00367	3	B+	
	25	1240	.00426	3	B+	

Table II. Retardation of Individual Pellets (Continued)

Rd. No.	Pellet No.	Velocity ft/sec.	α ft^{-1}	No. of timers	Condition	
7015	1	1190	.00382	4	B	slight flatness
	2	1184	.00394	4	B-	more flatness
	3	1184	.00396	4	C	oblong
	4	1188	.00444	3	C	oblong
	5	1184	.00452	3	D	battered
	6	1174	.00501	3	D	battered
	7	1199			D	oblong
	8	1182	.00396	5	C	battered
	9	1183	.00382	3	C	battered
	10	1174	.00499	3	D	battered
7018	1	1226	.00386		A	round-very slight bumpage
	2	1267	.00423	3	A	round-very slight bumpage
	3	1244	.00312		A	round-very slight bumpage
	4	1219	.00374		A	round-very slight bumpage
	5	1244	.00394	4	A	round-very slight bumpage
	6	1247	.00374	4	A	round-very slight bumpage
	7	1255	.00370	3	A	round-very slight bumpage
	8	1246	.00295		B+	round-slight dent
	9	1243	.00389	4	B+	round-slight dent
	10	1245	.00382	4	B+	round-slight dent
	11	1253	.00399	3	B+	round-slight dent
	12	1249	.00410	3	B+	round-slight dent
	13	1254	.00393	3	B	round
	14	1248	.00416	3	B	round
	15	1251	.00363	3	B	round
	16	1238	.00318	3	B	round
	17	1247	.00403	3	B	
	18	1236	.00487	3	B	
	19	1238	.00406	3	B	
	20	1239	.00377	3	B	

Table II. Retardation of Individual Pellets (Continued)

Rd. No.	Pellet No.	Velocity ft/sec.	α ft^{-1}	No. of timers		Condition
7018	21	1248	.00408	3	B	
	22	1245	.00631	3	B	
	23	1249	.00720	3	B	
	24	1250	.00454	3	B	
	25	1253	.00196	3	B	
	26	1247		2	B	
	27	1246		2	B	
7019	1	1211	.00382	4	A-	slightly out of rd.
	2	1214	.00356	4	B	flat side 16/12 = D_2/D_1
	3	1208	.00393	4	B+	oblongish
	4	1197	.00377	4	A-	slight dent
	5	1207	.00392	4	B+	dent
	6	1201	.00384	4	B	squash
	7	1215	.00422	4	B+	squash
	8	1195	.00384	4	B	dent
	9	1194	.00362	4	B-	flat side
	10	1221	.00351	3	C+	14/11 = D_2/D_1
	11	1198	.00386	4	B+	slight dent
	12	1192	.00378	4	B	dent
	13	1207	.00408	3	B	squash
	14					
	15	1208	.00355	4	A-	slight bump
	16	1213	.00384	3	A-	slight bump
	17	1204	.00373	3	B+	slight bump
	18	1206	.00404	3	B+	squash
	19	1198	.00403	3	A-	round
	20	1199	.00363	4	A-	round
	21	1205	.00344	4	A-	round
	22	1206	.00407	3	B+	round
	23	1207	.00350	3	B+	round
	24	1199	.00471	3	A-	round

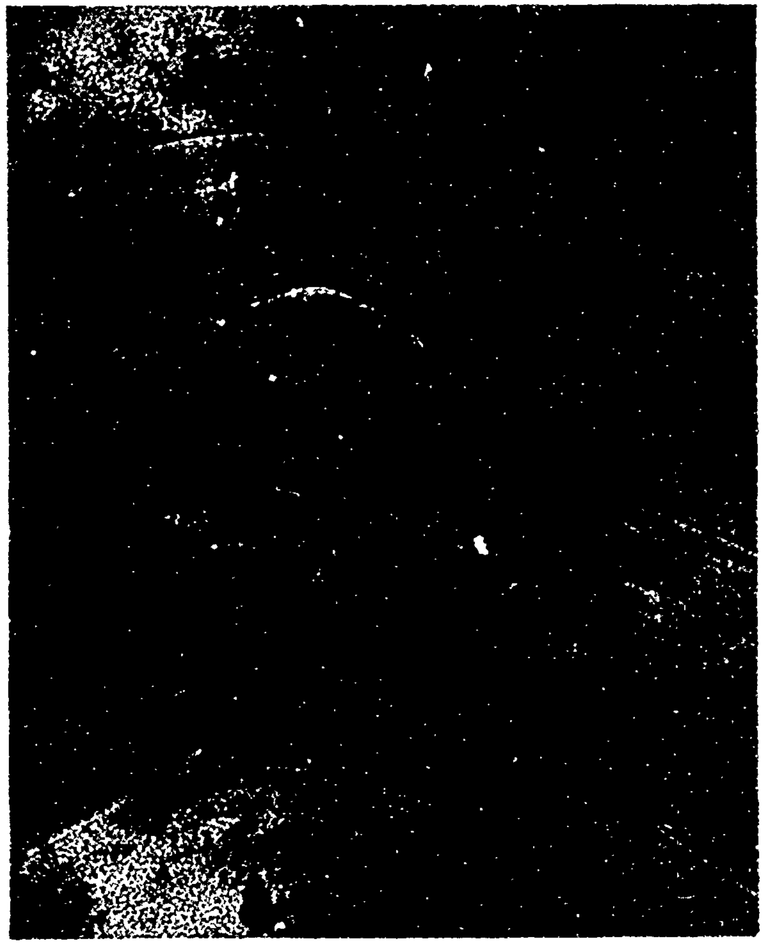
variety of grades. Thus it is believed that the variations indicated in the table are representative. A summary for the five rounds is given below, and it should be noted that Round 7015, AP 12 is the only case where some form of shot protective mechanism was not used.

Round No.	Loading*	Choke	Number of Pellets Identified (of 27)	Condition			
				A	B	C	D
7012	Exp	No	10	8	2		
7014	SL 227	No	25		25		
7015	SP 12	No	10		2	4	4
7018	Exp	Yes	27	7	20		
7019	SL 223	Yes	24	8	15	1	

As regards position and damage of the pellets, the following remarks can be made:

- The unprotected shot charge, SP 12, experienced more damage when fired with no choke than did the other charges fired from any choke condition.
- There is some indication that the choke produced more damage with the protected charges; however, the sample is so small that shot-to-shot variations are not excluded.
- Within the initial 30 feet of trajectory, there was a tendency for the shot string to form two groups with no determinable difference in averaged retardation or pellet conditions between the two groups. See Figures 7 and 8.
- Within the groups, there was often positional interchange. The initially leading pellet seldom retained this position beyond 20 feet from the muzzle.

** A description of loading is found in the Appendix.*



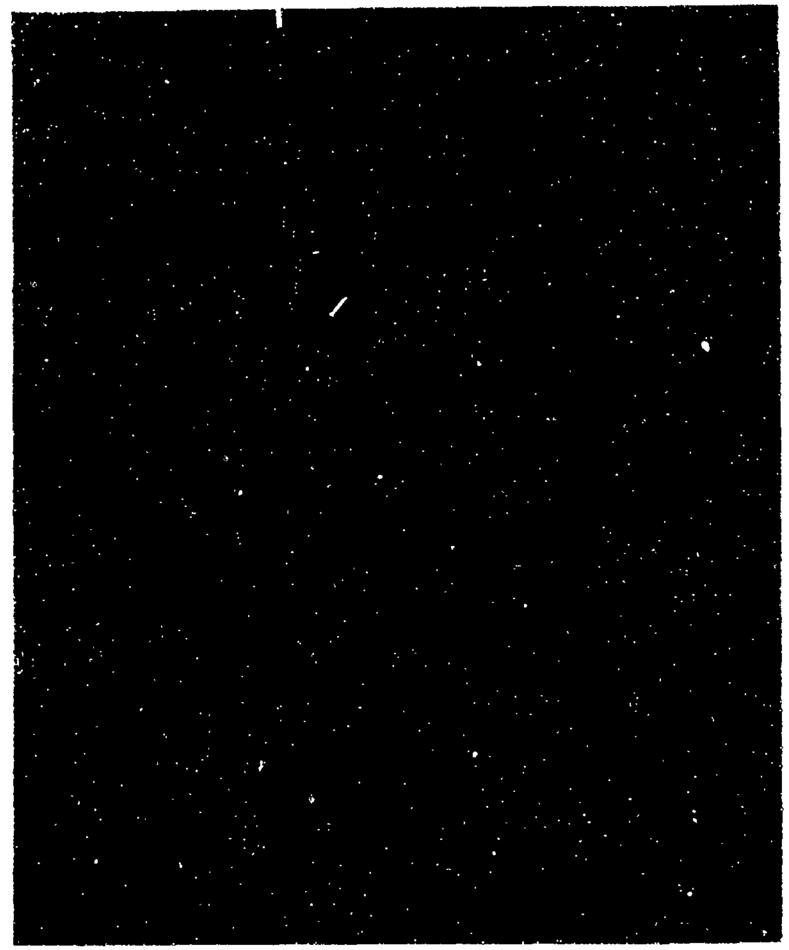


Figure 7 Station 2-H Figure 8 Station 2-V

Round 7014

Partition into two groups. Pellets 1-14 leading and pellets 15-26 trailing.

IV. EVALUATION OF THE AERODYNAMICS OF THE PELLET FLIGHT

The shot charge is launched at low supersonic speed (1100-1200 feet per second) and decelerates rapidly. In this velocity regime, the drag coefficient of a sphere or a cube would change by 50 percent. Over the range explored in these tests, changes of 20 percent would be expected. Hence, any values obtained are mean values.

The spread of the charge meant that individual pellets rarely passed through more than a minimal number of timing stations and hence some individual retardation determinations may simply be wrong. Five stations are usually considered the minimum.[6] Conversion of the measured retardation into the usual aerodynamic parameter, drag coefficient (C_D), poses a problem in definition. C_D is defined as:

$$C_D = \frac{\text{Drag Force}}{(1/2)\ \rho V^2 S}$$

where the density, ρ, is that of the undisturbed air, the velocity, V, is with respect to the undisturbed air, and S is an area directly related to the projectile geometry. C_D is expected to vary with Mach Number and Reynolds Number which, in turn, are related to the acoustic and viscous properties of the air. In the case of the single projectile, the relation between the properties of the undisturbed air and those of the disturbed air around the projectile is unique but in the case of multiple pellets the local conditions can be influenced by the behavior of the sibling pellets.

Values for the retardation, in terms of loss of velocity per foot of travel, were computed for all identified pellets that traversed three or more timing stations. For pellets covering only three stations, the data was handled by double differencing or numerical differentiation - where the velocities determined from the differences in distance and time for two sets of measuring stations are then subtracted to establish the change in velocity between their midpoints. The retardation coefficicent, α, is given by:

$$\alpha = \frac{dv}{Vd_Z}\ ft^{-1}$$

where V is the representative velocity within the flight interval and $dV/_{dZ}$ is the velocity gradient along the range.

The expression C_D can then be written as:

$$C_D = \frac{2m\alpha}{\rho S}$$

where ρ = air density (taken as undisturbed value),

m = mass of pellet, and

S = reference area of pellet (taken as the cross sectional area of the unfired pellet).

For the No. 4 shot used, the average pellet weight was taken to be 20 grains and the average diameter as 0.24 inch so that

$$C_D = 242.78\ \alpha\ .$$

The values of the retardation are given in Table I for the different categories of pellets, and in Table II for each individual determination. A comparison of the indicated C_D values with those for individual spheres and cubes is shown in Figure 9. As indicated, both these values and the Mach Number basis on which they are plotted are based on free stream properties, although a review of Figures 1 through 8 will show that only the leading envelope of pellets is moving into undisturbed air. The rest of the pellets, for the initial 40 feet observed, are in a local environment influenced by the heterogeneous shock structure of the group and by the wake of the leading pellets.

As regards the aerodynamic effects, the following observations can be made:

- Pellets with small to medium damage yield retardation and C_D values which, in general, are slightly higher than those of a corresponding sphere.[7]

- Major pellet deformation is associated with retardations and drags from 20 to 30 percent higher than those of a sphere. Lesser damage levels give no strong correlation.

DRAG COEFFICIENT
VS
MACH NUMBER

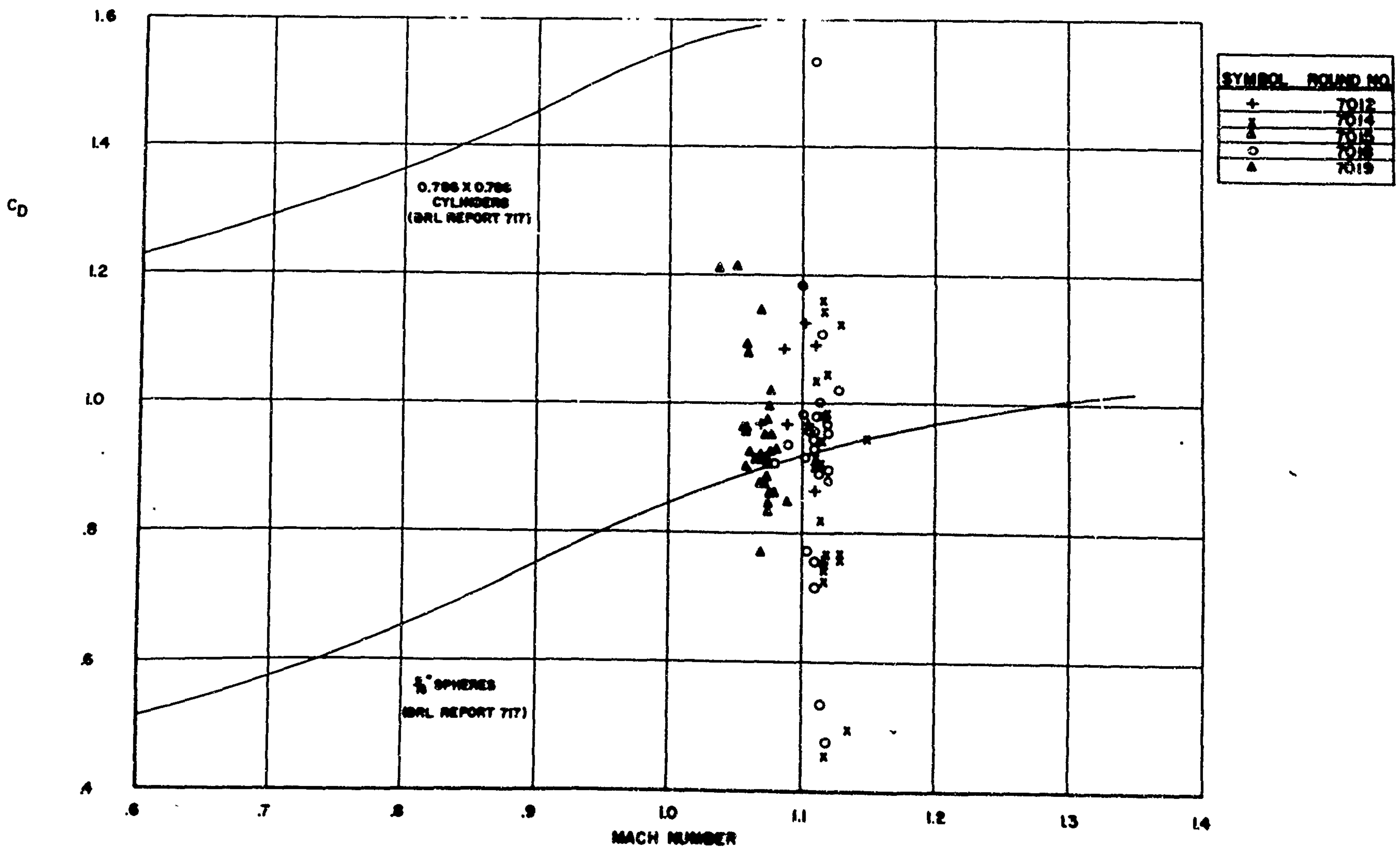


Figure 9

C_D BASED ON FREE STREAM AIR DENSITY

- A few pellets exhibit a drag coefficient lower than that of a sphere at the same Mach Number. In at least one case, this was due to one pellet's close pursuit of, and probable contact with, another pellet. Other causes can be suggested:

  a. The individual pellet is in an induced velocity region such that the velocity with respect to the air is less than that with respect to the ground; and thus the pellet would have a low apparent drag coefficient. A similar argument could be applied to the effect of a density change.

  b. The local Mach Number for the pellet may be less than the free stream value and hence the C_D value is plotted at a lower value than would be expected. The shock wave patterns shown in the shadowgraphs suggest that this does occur. The effect of Reynolds Number changes could also produce an increase or decrease in the C_D value, and since R_e was not used as a variable, its effect would simply be added scatter.

It should be noted that the results shown, particularly when presented as a function of velocity or Mach Number, are conditioned by both damage level and the degree of interaction occurring. The damage is a function of the launching load, and the region of interaction will be influenced by the distance from the gun and the muzzle velocity. Direct extrapolation of these results to other conditions is not recommended.

V. COMMENTS ON PROCEDURE

The technique of firing charges of pellets, tracking them, and determining their properties by use of the spark shadowgraphic stations of the range is feasible. Among the limitations and drawbacks, the information on the following page should be noted:

- The loss of members of the shot group with increasing range means that tests over a longer distance than the 40 feet used in the Aerodynamics Range might provide non-representative pellet samples.
- The processing of a single round requires a large amount of human effort which does not seem to lend itself to mechanization. Hence, the process cannot be recommended for routine data acquisition unless the probable importance of the results is high.

REFERENCES

1. C. M. Sabin, "The Effects of Reynolds Number, Mach Number, Spin Rate, and Other Variables on the Aerodynamics of Spheres at Subsonic and Transonic Velocities," Ballistic Research Laboratories Memorandum Report No. 1044, November 1956.

2. C. H. Murphy, "Free Flight Motion of Symmetric Missiles," Ballistic Research Laboratories Report No. 1216, page 26, (extract from Reference 3).

3. A. May and W. R. Witt, Jr., "Free Flight Determination of the Drag Coefficient of Spheres," Journal Aero Sciences, Vol. 20, pages 635-638, September 1953. (Also published as NAVORD Report 2352, August 1952.)

4. W. K. Rogers, "The Transonic Free Flight Range," Ballistic Research Laboratories Report No. 1044, June 1958.

5. W. F. Braun, "The Free Flight Aerodynamics Range," Ballistic Research Laboratories Report No. 1048, July 1958.

6. B. G. Karpov, "The Accuracy of Drag Measurements as a Function of Number and Distribution of Timing Stations," Ballistic Research Laboratories Report No. 658, February 1948.

7. E. Richards, "Comparative Dispersion and Drag of Spheres and Right Cylinders," Ballistic Research Laboratories Report No. 717, March 1950.

APPENDIX

Description of Gun

For rounds No. 7012 through 7015

Winchester Model 12, 21-inch barrel, cylinder bore, Riot shotgun, Serial No. 988820.

For rounds No. 7017 through 7019

Winchester Model 12, 24-inch barrel including choke, Riot shotgun with variable "Polychoke" set at "Full choke" position, Serial No. 955184.

Description of Pellet Charge

Exp. - Winchester P. O. SA 3-00453, lot WCG Pilot B 12 ga Super X for 2.75-inch chambers, 27 pellets of No. 4 buckshot. This is an experimental loading in a case having a plastic body and a brass head. Pellets are surrounded by the Mk 5 polyethylene collar and the intertices in the shot column are filled with a powdered plastic. The pellets are hardened by the addition of approximately 4 percent antimony.

SP 12- 12 ga 3.75 dram equivalent for 2.75-inch chambers. 27 pellets of No. 4 buckshot. This is a standard off-the-shelf shotshell packaged case having a polyethylene body and a brass-washed steel head. The end of the shell is closed in a roll casing and a plastic top wad.

SL 227-These are SP 12 with silicon rubber (RPD 11) impregnation.
and 223.

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13. ABSTRACT

In any estimate of the trajectories of shot fired from a shotgun, the drag of the system of pellets might be expected to vary with the degree of damage incurred by the pellets and with the Mach and Reynolds Numbers. Results of experiments are presented for representative shot fired from a riot gun for five loading conditions. Pellet distributions, damage incidence, and aerodynamic retardations are determined from spark shadowgraphic traces. Pellets with severe launch damage indicate higher drag than corresponding spheres launched individually.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Spheres Pellets Drag Shotguns Trajectory Small Arms Infantry Weapon						

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