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STABILITY OF 90 MM SHELL T8

by

H. P. Hitchcock

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U.S. ARMY ABERDEEN RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

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STABILITY OF 90 MM SHELL T8

ABSTRACT

It is found that the stability factor of the 90 mm H.E. Shell T8 with the Mechanical Time Fuze M43, fired from the 90 mm A.A. Gun M1, which has a twist of rifling of 1/32, is 1.32 at a muzzle velocity of 2700 ft/sec. A twist of 1/30, which would make the stability factor 1.50, is recommended.

TABLES

Firing Record No. 23,858

1. AUTHORITY: This test was authorized by letter O.O. 471.91/805 (APG 471/1143-44).

2. OBJECT: The object of this test is to determine the stability factor of the 90 mm H. E. Shell T8 with the Mechanical Time Fuze M43, fired from the 90 mm A.A. Gun M1. This shell is a modification of the A.A. Shell M58 (T3) whose stability factor was found to be 1.33 for a twist of 1/32.*

3. GUN: 90 mm A.A. Gun M1 No. 23, with tube No. 24, rifled with a twist of 1 turn in 32 calibers.

4. SHELL: 90 mm Shell T8, loaded with red lead and paraffin. Some TNT loaded shell were also measured for comparison, but not fired in this test.

5. FUZE: Mechanical Time Fuze M43. The TNT loaded shell were fitted with M43 A1 fuzes.

6. POWDER: 6 lb. 13 oz. DP powder lot 3927-41 for 90 mm Gun M1, to give a muzzle velocity of 2700 ft/sec.

7. VELOCITY: The velocity was measured with a solenoid chronograph. The first coil was 89.75 feet from the muzzle, and the distance between coils was 101.75 feet. Some cardboards placed between the coils caused a slight error in the velocity. The velocity was lost on six rounds because the circuit was improperly closed: this operation was performed by touching the ends of two wires together. The average of the four muzzle velocities obtained is 2705 ft/sec.

8. YAW SCREENS: The gun was emplaced at the railway range, so that some of the yaw screens could be put into permanent frames. Other cardboards were fastened to movable frames. The screen distances for dense distribution are given in Table I. For sparse distribution, stations 2, 3, 4, 7, 8, 9, 15, 16, 17, 19, 20, 21 were used.

9. FIRINGS: Five shell were fired thru the dense distribution of yaw screens, and five thru the sparse distribution. On the second round, the yaws near the end of the range were too small to give reliable results. On the fifth round, the last two yaws were no good because the shell hit a frame, but satisfactory data were obtained from the other screens. Excepting round 2, the first maximum yaws were between 10° and 14°, and the damping was quite rapid.

10. DYNAMIC DATA:

A. In order to obtain large enough yaws to measure accurately, the bourrelet and the flat behind the rotating band of each inert

* H. P. Hitchcock, "Stability of 90 mm Shell T3", APG, BRL Report No. 165, 1939.

loaded shell were machined to a diameter of 3.520 - .005 inches. These diameters, as well as the lengths of the fuzed shell, the flat behind the band, and the boat-tail, were then measured, and the dynamic data determined. Similar measurements and dynamic data were also determined for six TNT loaded shell. The center of gravity and moments of inertia were determined in the manner explained in Ballistic Research Laboratory Report No. 150, allowing 0.005 $lb.ft^2$ as the axial moment of inertia of the fuze M43. The true width of the block used in measuring the center of gravity is 0.492; the value 0.748 was previously reported, but never used in the computations. However, the transverse moment of inertia of Mass A that was previously reported and used has been found to be erroneous: it should be 0.7653 $lb.ft^2$ instead of 0.7445 $lb.ft^2$.

b, The measurements of the shells are given in Table II. It should be noted that the reduction in the diameter behind the band increased the length of flat by about 0.06 inch.

c. The dynamic data are tabulated in Table III. The weight and axial moment of inertia of the inert loaded shell are practically the same as those of the H.E. shell. However, the red lead and paraffin brought the center of gravity 0.006 caliber (0.02 inch) towards the base, and decreased the transverse moment of inertia 0.017 $lb.ft^2$ (0.6%).

11. STABILITY:

a. The stability firing data are given in Table IV. The average observed rate of precession φ'/π is 0.011,60 semi-rev/ft, with a probable error of 0.000,017. The theoretical rate of precession, calculated by the usual formula

$$\varphi'/\pi = A/ndB$$

where

A is the axial moment of inertia,

B the transverse moment of inertia,

n the pitch of rifling,

d the caliber,

is 0.011,15 semi-rev/ft, with a probable error of 0.000,030. Hence, the ratio of the observed to the theoretical rate is 1.040. The agreement is usually, though not always, closer than this.

b. In order to see if this discrepancy is partly due to errors in the method, let us determine the precession more precisely. In the first place, since the projectile loses velocity along the trajectory, the precession should be referred to time instead of distance. In the present case, the orientations were measured with the greatest accuracy in the vicinity of the first and third maximum yaws. Therefore, we shall consider the average precession $\Delta\varphi$ during the two complete periods Δt from the first to the third maximum yaw.

c. The average observed period is 180 feet. The average maximum yaw is 11.8°. The muzzle velocity was taken as 2705 ft/sec. The form factor was assumed to be 0.77 relative to G_5: this was based on range firings of the M58 shell, and is applicable at low elevations. A yaw-drag coefficient of 0.005 per deg^2 was also used in obtaining the time of flight. Hence, we obtain the time interval:

$$\Delta t = 0.1345 \text{ sec.}$$

The average increase in orientation during this time, with one revolution added on account of the yaw passing through two minima, is:

$$\Delta\varphi = 4.176\pi = 13.12 \text{ rad.}$$

d. Since the minimum yaw is less than 1°, we can consider it 0 and use Fowler's approximate formula* for the derivative of the orientation:

$$\frac{d\varphi}{dt} = \frac{AN}{B} \quad \frac{1}{1 + \cos\delta} .$$

The yaw varies periodically between the minimum and the maximum, whose average value in this case is

$$\alpha = 11.8°.$$

A good approximation of the difference in orientation during two complete periods may then be obtained by the formula:

$$\Delta\varphi = \frac{AN}{B} \quad \frac{\Delta t}{1 + 0.5(1 + \cos\alpha)} .$$

In the present case, the value of the last factor is:

$$\frac{\Delta t}{1 + 0.5(1 + \cos\alpha)} = \frac{0.1345}{1.9895} = 0.0676 \text{ sec.}$$

* R. H. Fowler, E.G. Gallop, C.N.H. Lock and H. W. Richmond, "The Aerodynamics of a spinning shell", Phil. Trans. Royal Soc. London, A, 221, 295-387 (1920): formula (3.701).

e. The spin at the muzzle is precisely determined by means of the formula:

$$N_o = 2\pi(v_o + v_r - v_b)/nd$$

where

N_o is the muzzle spin,

v_o the muzzle velocity, as usually determined from the instrumental velocity at some distance in front of the muzzle,

v_r the recoil velocity of the gun,

v_b the increase in projectile velocity caused by the blast.

Although the terms in v_r and v_b are usually omitted, Kent has pointed out that they should be included in this formula.

f. The recoil velocity approximately satisfies the relation:

$$v_r = \frac{p + c/2}{R} v_o$$

where

p is the weight of the projectile,

c the weight of the charge,

R the weight of the recoiling parts.

Since the recoiling parts of the 90 mm Gun M1 weigh 2445 lb, in the present case, the recoil velocity is 29 ft/sec.

g. The spin of an experimental 3.3" Shell Type 68, fired from the 3.3" Field Gun M1919 No. 3 which weighed 1512 lb, was observed at ranges in the vicinity of 120 and 930 feet. By extrapolation, Kent* found the muzzle spin to be 1813.3 rad/sec. Using the instrumental velocity at 90 feet, measured by the Boulengé chronograph, and other data given in Kent's report, it is found that the nominal muzzle velocity is 2015 ft/sec. In this case, the recoil velocity of the gun is 24 ft/sec. Hence, the muzzle spin, calculated by the approximate formula:

* R. H. Kent, "A determination of the loss of spin of projectiles", APG B.R.L. Report 154 (1939).

$$N_o \approx 2\pi(v_o + v_r)/nd,$$

is 1863.5 rad/sec. The ratio of the empirical to the calculated muzzle spin is 0.973. Although the effect of the blast depends on the muzzle pressure, we shall assume that this ratio applies to the 90 mm gun. For that gun, under the present conditions, the muzzle spin is

$$N_o = 1769 \text{ rad/sec.}$$

h. The spin at a short distance from the muzzle may be found approximately by Kent's formula:*

$$\log_e N = \log_e N_o - \frac{K_A \rho d^4}{A} x,$$

where

N is the spin,

K_A the "axial couple coefficient",

ρ the air density,

d the caliber,

A the axial moment of inertia,

x the distance.

Kent derived the value of an "axial couple coefficient"

$$C_A = 1.74 \times 10^{-8} \text{ lb.ft/in}^4$$

with ρ as the ratio of air density to the standard, which is 0.07513 lb/ft^3, d measured in inches, A in lb.ft^2, and x in ft. The corresponding non-dimensional coefficient is

$$K_A = 0.0048.$$

In the present case, with the average air density ratio of 0.986, at the average range of 270 feet,

$$N = 1764 \text{ rad/sec.}$$

* loc. cit.

i. We now have sufficient data to determine the theoretical increase in orientation:

$$\Delta\varphi = 12.57 \text{ rad.}$$

The ratio of the observed to the theoretical rate is 1.044, which is about the same as the less precise value. Part of this discrepancy may be due to the error in assuming that the ratio of the actual to the calculated muzzle spin is the same for the 90 mm gun as for the 3.3" gun: probably it should be higher for the former since the linear velocity of the projectile is higher relative to the gun and presumably also relative to the gas. Also the loss of spin was not determined very accurately: so this may lead to a further error.

j. Since the average temperature was 74°F, the velocity of sound was 1134 ft/sec. Taking 2705 ft/sec as the muzzle velocity, the Mach number was 2.385.

k. The results of the stability firing are given in Table V. The cardboard constant was determined by the method of least squares.

l. The mean stability factor of the inert loaded 90 mm shell T8 is 1.321, with a probable error of 0.004. The moment coefficient is 1.25. Since the center of gravity of the H.E. Shell is farther forward than that of the inert loaded shell, the moment coefficient of the former would be slightly less; but its transverse moment of inertia is a little more, so its stability factor would be practically the same.

12. RECOMMENDATION: Although the 90 mm Shell is stable when fired from the A.A. Gun M1 at a muzzle velocity of 2700 ft/sec, its stability factor of 1.32 is considered rather low. This is nearly the same as that of the M58 Shell for the same twist. A twist of 1/30, which was recommended for the M58 Shell, would increase the stability factor to 1.50, and is also recommended for the T8 Shell.

H. P. Hitchcock

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TABLE I

YAW SCREEN DISTANCES

STATION NO.	DISTANCES (FT.)	
	BETWEEN SCREENS	FROM MUZZLE
1	----	61.7
2	11.5	73.2
3	15.5	88.7
4	20.0	108.7
5	20.0	128.7
6	20.0	148.7
7	20.0	168.7
8	20.0	188.7
9	20.0	208.7
10	61.3	270.0
11	88.0	358.0
12	20	378
13	20	398
14	21	419
15	20	439
16	20	459
17	20	479
18	20	499
19	20	519
20	20	539
21	20	559

TABLE II

MEASUREMENTS OF

90 MM SHELL T8, M.T. FUZE M43

Loading	TNT	Red lead and paraffin
Length of shell and fuze	16.27	16.26
Length of shell	12.51	---
Length of boat-tail	1.80	1.72
Length of flat behind band	0.87	0.93
Base to band	2.67	--
Width of band	1.20	--
Diameter of bourrelet	3.534	3.518
Diameter in front of band	3.510	---
Diameter behind band	3.533	3.519
Diameter of rotating band	3.637	---
Number of projectiles	6	10

All dimensions in inches.

TABLE III

DYNAMIC DATA

90 MM SHELL T8, M.T. FUZE M43

Loading	Shell No.	Weight	C.G. to base (cal.)	Moments of Inertia ($lb.ft^2$) Axial	Moments of Inertia ($lb.ft^2$) Transverse
Red lead and paraffin	1	23.16	1.739	.2740	2.601
	2	23.20	1.736	.2758	2.614
	3	23.19	1.741	.2756	2.597
	4	23.20	1.735	.2752	2.605
	5	23.16	1.745	.2738	2.608
	6	23.16	1.733	.2756	2.607
	7	23.22	1.731	.2745	2.670
	8	23.20	1.730	.2755	2.602
	9	23.22	1.740	.2750	2.605
	10	23.17	1.734	.2756	2.597
	Ave.	23.19	1.736	.2751	2.611
TNT	1	23.38	1.744	.2775	2.654
	2	23.25	1.739	.2768	2.634
	3	23.22	1.746	.2752	2.624
	4	23.20	1.735	.2747	2.622
	5	23.16	1.745	.2744	2.622
	6	22.92	1.743	.2730	2.606
	Ave.	23.19	1.742	.2753	2.627

TABLE IV

STABILITY FIRING DATA

90 MM SHELL T8, LOADED WITH RED LEAD AND PARAFFIN, M.T. FUZE M43

Rd. No.	Shell No.	Yaw (deg.) First Max. α_1	Yaw (deg.) Last Max. α_n	Yaw (deg.) First Min. β_1	Yaw (deg.) Last Min. β_n	Muzzle to Min. Yaw (ft.) First m_o	Muzzle to Min. Yaw (ft.) Last m_n	Number of Periods n	Precessions (semi-rev/ft) φ'/π	Correction Factor* $\frac{\Sigma(\delta/\alpha)^2}{n}$	Air Temp. °F	Air Density ratio
1	10	12.5	10.0	0	0	0	559	3	.01172	3.29	72	0.990
2	9	7.0							.01160			
3	8	13.7	10.8	0	0	0	378	2	.01153	2.72	74	0.986
4	7	10.0	8.1	0	0	0	378	2	.01166	2.95	74	0.985
5	6	14.2	11.7	0	0	0	358	2	.01169	2.67	74	0.986
6	1	13	13	0	0	0	180	1	.01144	2.85	74	0.986
7	2	12.2	8.8	0	0	0	527	3	.01156	1.72	74	0.986
8	3	11.9	9.4	0	0.6	188	526	2	.01174	1.22	74	0.986
9	4	9.6	7.9	0	0	189	549	2	.01158	1.48	75	0.984
10	5	9.5	8.3	0	0	191	542	2	.01144	1.42	75	0.984

*δ is yaw at yaw screen

α is the maximum yaw

α_1 and α_n are interpolated values at m_o and m_n.

TABLE V

STABILITY RESULTS

Round No.	Average Period (ft.)	Cardboard Constant	Period Without Cards	Stability Factors			Yaw Screen Distance
				Without Cards	At Muzzle	At normal Air density	
	L_a	c	L_c	s_c	s_o	s_ρ	
1	186.3	6.41	165.21	1.353	1.331	1.318	Dense
3	189.0		171.56	1.330	1.315	1.297	"
4	189.0		170.09	1.334	1.319	1.301	"
5	179.0		161.89	1.372	1.357	1.338	"
6	180.0		161.73	1.396	1.389	1.370	Sparse
7	175.7		164.67	1.371	1.350	1.331	"
8	169.0		161.18	1.377	1.348	1.329	"
9	180.0		170.51	1.338	1.309	1.288	"
10	175.5		166.40	1.379	1.349	1.327	"
Mean (Rds. 1-6, 1/2 weight)						1.321	

ABERDEEN PROVING GROUND FIRINGS

Object of Firing: Stability Test of New 90 m/m Shell

Date of Firing June 6, 1941
Firing Record No. 23858
Sheet 1 of 5
T. S. T. P.
O. C. M. Item
O. P. No. 5420
Container No.
O. O. File
A. P. G. File
W. O. No. 202-13-1 Gjr

DEVELOPMENT

Related F. R. Nos.

	CALIBER	MODEL	MANUFACTURER	No.	ROUNDS FIRED PRIOR TO TEST
Cannon	90 m/m Tube 90 m/m Gun	M1 M1	Watervliet Arsenal Watervliet Arsenal	24 23	287 287
Carriage	90 m/m Gun	M1	Watertown Arsenal	6	
Recoil Mech	90 m/m Gun	M1	Watertown Arsenal	5	

Azimuth of line of fire 400 | Deflection AP Mils

Gun position R. R. Range | Target

Projectile
M58, B.W. Lot 465-1 (Rd. 288)
90 m/m T8 (Modified) Lot 6666-262 (All other rounds)

Bursting charge

Adapter ~~xxxxxx~~
Wood Plug (Rd. 288)

Fuze
M43A1 Lot 1782-15 (Rd. 288)
M43 Mech. Time (Insert) P.A. Lot 279-3 (All other rounds)

Powder
DuPont NH Smokeless Powder M1, Picatinny Arsenal Lot X-3927 of 1941 for 90 m/m A. A. Gun, M1

Case ~~xxxxx~~ 90 m/m, M19

Igniter

Primer M28A1, 300 Gr. P.A. Lot 4946-6

ABERDEEN PROVING GROUND FIRINGS

GENERAL DATA BY ROUNDS

1941 DATE June	ROUND No.	TIME OF FIRING	PROJECTILE APG No.	PROJECTILE Weight as Fired Lbs.	PROJECTILE Ozs.	POWDER Lot	POWDER Box No.	POWDER Charge Weight Lbs.	POWDER Charge Weight Ozs.	ELEVATION Deg.	ELEVATION Min.	Measured Pressure	Measured Velocity Sol.
6	288	10:48				X-3927		5	0	10	0		
	289	10:54	10	23	2.5	"		6	13	0	-18	36900	2704
	290	11:29	9	23	3.25	"		"	"	"	"	37600	2700*
	291	11:48	8	23	3.0	"		"	"	"	"	38000	2700*
	292	12:07	7	23	3.25	"		"	"	"	"	38700	2705
	293	1:18	6	23	2.5	"		"	"	"	"	37700	2700*
	294	1:47	1	23	2.5	"		"	"	"	"	38800	2700
	295	2:03	2	23	3.5	"		"	"	"	"	37100	2700*
	296	2:18	3	23	3.25	"		"	"	"	"	37700	2700*
	297	2:27	4	23	3.5	"		"	"	"	"	38000	2709
	298	2:42	5	23	2.75	"		"	"	"	"	36900	2700*

* - Estimated (Lost)

ABERDEEN PROVING GROUND FIRINGS

F. R. No. 23353
Sheet 3 of 5

VELOCITY DATA

Cannon 90 m/m Tube, Bl, No. 24 Fired by Lt. R.V.Mackey, Jr. co June 6, 1941

Screen Distances	Gun to first	Horizontal	Corrected to	Between	Horizontal	Corrected to
	Coil	89.75'		Coil	161.75'	
	Screen			Screen		

Round No.	Time of Firing	Form Factor	Boulengé Chronograph No.			Mean Instrumental	Muzzle Velocity	Solenoid Instrumental	Solenoid Muzzle Velocity
289	10:54	i=.77(G5)						2690	2704
290	11:29							----	Lost
291	11:48							----	Lost
292	12:07							2692	2706
293	1:18							----	Lost
294	1:47							2686	2700
295	2:03							----	Lost
297	2:27							2695	2709
298	2:42							----	Lost

ABERDEEN PROVING GROUND FIRINGS

PRESSURE DATA

Type of gauge Medium Caliber
Position of gauge In base of cartridge case.
Metal of crusher cylinder 1919 Reannealed, Inspected and Gauged at Frankford 12/40 & 1/41
Initial compression 0

ROUND No.	BAND DIAM. INS.	GAUGE No.	PRESSURE 100	GAUGE No.	PRESSURE 100	GAUGE No.	PRESSURE 100	GAUGE No.	PRESSURE 100	MEAN
289		457	366	212	372					369
290		320	380	422	372					376
291		323	376	425	384					380
292		363	394	327	380					387
293		108	378	65	376					377
294		275	386	136	390					388
295		279	362	376	380					371
296		138	376	265	378					377
297		1	384	340	376					380
298		99	380	479	358					369

Pressures in this report are read and calculated to the nearest 100 lbs.

ABERDEEN PROVING GROUND FIRINGS

F.R. No. 23858
Sheet 4A of 5
Date June 6.194

JUMP DATA

for

90 m/m Gun, M1, No. 23 Mfg. by Watervliet Arsenal (Twist 1/32)

mounted on

90 m/m Gun Carriage, M1, No. 6, Mfg. by Watertown Arsenal

Projectile 90 m/m T8 (Modified) Lot 6066-262

Fuze M43 Mech. Time (Inert) F.A. Lot 299-3 Weight of charge 6 Lb. 13 Ozs.

ROUND No.	Gun to Screen	MAJOR AXIS (Cals.)	YAW	ORIENTATION	X (Inches)	Y (Inches)	JUMP, IN MINUTES	
							Hor.	Vertical
	Feet							
289	61.7	4.83		278	+ .37	-1.19		
290	"	3.84		203	+ .47	- .70		
291	"	4.77		338	- .27	-1.07		
292	"	4.32		11	0	- .70		
293	"	4.98		167	+ .24	0	+ .66	-2.60
294	73.2	5.19		13	- .46	- .75		
295	"	4.84		8	- .89	-1.12		
296	"	5.08		32	- .72	- .89		
297	"	4.63		40	0	- .39		
298	"	4.67		287	+ .18	-1.29	-1.34	-2.64

NOTE.—X and Y are rectangular coordinates of the center of impact, the origin being the intersection of the prolongation of the axis of the bore with jump car [illegible]

MISCELLANEOUS DATA

The 10 test projectiles had been machined to give a diameter of bourrelet and below rotating band of 3.520 - .005".

The cardboard screens were placed at the following distances for dense distribution:

Muzzle to 1	61.7'	Muzzle to 12	378.0'
2	73.2'	13	398.0'
3	88.7'	14	419.0'
4	108.7'	15	439.0'
5	128.7'	16	459.0'
6	148.7'	17	479.0'
7	168.7'	18	499.0'
8	188.7'	19	519.0'
9	208.7'	20	539.0'
10	270.0'	21	559.0'
11	358.0'		

For Sparse Distribution screen numbers 2, 3, 4, 7, 8, 9, 15, 16, 17, 19, 20, and 21 were used.

APPROVED:
J. B. ROSE,
Brigadier General
Commanding

BY:
WM. B. HARDIGG,
Col., Ord. Dept.,
Officer in Charge
of Proof Dept.

G. G. Eddy
G. G. EDDY,
Maj., Ord. Dept.,
Chief Proof Officer
Arms & Ammun. Div.

R. V. Mackey Jr.
R. V. MACKEY, JR.
2nd. Lt. Ord. Dept.
Proof Officer