REPORTS ON EXPERIMENTS MADE WITH THE BASHFORTH CHRONOGRAPH TO DETERMINE THE RESISTANCE OF THE AIR TO THE MOTION OF ELONGATED PROJECTILES. PART II. 1878-79

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FRANCIS BASHFORTH

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Trieste

REPORT

ON

EXPERIMENTS MADE WITH THE BASHFORTH CHRONOGRAPH.

TO DETERMINE

THE RESISTANCE OF THE AIR TO THE MOTION OF ELONGATED PROJECTILES.

(PART II.)

1878–79.

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REPORT VIII.

MINTING VICARAGE, HORNCASTLE,
July 8, 1879.

SIR,

THE experiments made with the Bashforth Chronograph in 1867–68, to determine the resistance of the air to the motion of projectiles, showed that this resistance to similarly shaped shot varied as the squares of their diameters, but that the resistance to a given shot did not vary according to any simple power of the velocity. The most convenient form in which the resistance could be expressed was found to be $2b'v^3$, where v is the velocity of the shot expressed in feet per second, and b' is a coefficient which generally varies slowly with v. Tables of corresponding values of v and b' were derived from experiments made with spherical shot, between velocities 850 and 2150 f. s.; and with elongated ogival-headed projectiles, between velocities 900 and 1700 f. s. At that time this velocity of 1700 f. s. was considered to be sufficiently high for all practical purposes. The experiments stopped at a velocity about 900 f. s., because the trajectory became much curved, and the results obtained with screens 150 feet apart were not satisfactory for lower velocities. The reports of these and some other experiments made with the same chronograph were printed and published in 1870* (84/B/1941).

In 1877 it was decided to continue these experiments with ogival-headed shot moving at *low* velocities. The screens were placed 75 feet apart, instead of 150 feet as before. They were 16 in number, instead of 10 as before, many of them being much higher. The threads of the screens were placed one inch apart, instead of two inches. All these changes greatly increased the labour and difficulty in carrying out the experiments with low velocities.

As the resistance of the air had been found to vary as the square of the diameter of the shot in the former experiments, it was decided to make use now of only one gun, rifled with a rapid twist in order to obtain steadiness in the shot fired with a low initial velocity, and also to obtain results corresponding to those which might be expected to be derived from the terminal motion of a shot fired with a high initial velocity from an ordinary service gun. The gun selected was the small 7 pr. R.M.L. gun, firing hollow shot of weights varying from 6·31 to 6·66 lbs. The

* Reports on Experiments made with the Bashforth Chronograph to determine the Resistance of the Air to the Motion of Projectiles, 1865–1870. London: W. Clowes and Son; Harrison and Sons; W. H. Allen and Co.; W. Mitchell; Longmans and Co.; Trübner and Co. Edinburgh: A. C. Black. Dublin: A. Thom and E. Ponsonby.

shot were 2·94 inches in diameter, but as the gas-check continued attached to the shot, d was taken equal 2·97 inches. Rounds 412–438 were fired through all the 16 screens. For rounds 439–448 the screens Nos. 10, 11, and 12 were left out. The heights at which the screens were cut were carefully noted after each round, so as to give the means for forming an average trajectory for each charge used. Thus the exact velocity could be obtained, because the chronograph gave the times between successive screens, and the average trajectory gave the spaces travelled over by the shot in those times. In order to obtain the resistance of the air to projectiles moving with still lower velocities, rounds 449–460 were fired from the 6·3-inch howitzer, the screens Nos. 6–11 having been removed. By interpolation, it was found at what times the projectiles were due at each screen, and then the times over the central screens, where the motion of the shot was nearly horizontal, were used in calculating the coefficient b'.

The chronograph was set up at Shoeburyness on the 18th of June, 1878, and experiments were carried on during the following three days, but with little success. In the first place, induced currents interfered with the working of the instrument. Then it was found that the shot 3 inches in diameter often passed between the threads only one inch apart without breaking one, and the gas-check sometimes left the shot in its flight. The rounds fired with 12 and 8 oz. charges were reduced. Some of the results were good, and some bad. The records obtained from rounds fired with 6 and 4 oz. were so defective that they could not be reduced with a prospect of any trustworthy result. The only way to proceed seemed to be to reject *all* these rounds rather than make a selection of what appeared to be good.

The screens were afterwards formed with sewing cotton instead of linen thread, but still, at low velocities, the 3-inch shot often passed through a screen without breaking a thread. It therefore seems desirable, in experiments with low velocities, that something should be attached to the front of the shot, which, while it did not sensibly affect the resistance of the air to the shot, would secure the breaking of the wires or threads of which the screens are composed. The whole of the subsequent rounds were reduced where possible, and the results have been stated in all cases in the following tables. It seemed desirable to reject two very defective rounds, 420 and 431, fired from the 3-inch gun, which appeared to give too high a resistance. Also, for the same reason, two rounds from the 6·3-inch howitzer, 455 and 460, were rejected, for they indicated a resistance much too great in comparison with other rounds. This may have arisen from some error or from great unsteadiness of the shot.

The lower the velocity of the shot the less the motion of the shot is affected by the resistance of the air. This, added to the increased curvature of the trajectory of the shot for low velocities, renders the correct determination of the resistance of the air a matter of great labour and difficulty at low velocities. A reference to Table III will show that the values of K_v for velocities below 550 f. s. cannot be considered to be conclusively determined because they depend upon so few rounds. The results have been given as they presented themselves, and they appear to agree with the more trustworthy results obtained with higher velocities. If these values of K_v may be relied upon, the resistance of the air varies as the *square* of the velocity for velocities 430 to 830 f. s., and as the *cube* of the velocity from 830 to 1000 f. s.

As the resistance of the air has only a slight effect upon heavy shot moving at low velocities, it is probable that, in this respect, all has been accomplished that is of practical utility.

In consequence of recent improvements in guns and powder, giving greatly increased muzzle velocities, it was thought desirable to determine the values of b' or K_v for all possible velocities above 1700 f. s. Rounds 461–463 and 470–482 with ogival-headed shot, rounds 464–466 with flat-headed shot, rounds 467–469 with hemispherical headed shot were fired from Armstrong's new 6-inch B.L. gun, through 12 equidistant screens (150 feet apart). These rounds gave values of K_v or b' for ogival-headed shot up to 2250 f. s. These values of K_v or b' appear to be continually tending to become constant as the velocity increases up to 2250 f. s. In default, therefore, of experiments with higher velocities, we may consider K_v to continue constant and equal $K_{2250} = 66{\cdot}6$ for all velocities of ogival-headed projectiles exceeding 2250 f. s. For suppose a shot fired with a muzzle velocity of 2500 f. s., this would be reduced in a very short interval of time below 2250 f. s. where the coefficient is known from actual experiment.

During some of these experiments, two Le Boulengé chronoscopes were used in addition, to measure the velocities of the shot at 150 and 1650 feet from the gun. The following are the results given by the two instruments :—

	No. of Round.									
	461	462	463	464	465	466	468	469	470	472
	f. s.	f. s.	f. s.	f. s.	f. s.	f. s.	f. s.	f. s.	f. s.	f. s.
Bashforth	1946	1935	1942	1905	1897	1880	1889	1912	1778	1764
Boulengé	1947	1928	1848	1907	1882	1880	1917	1912	1778	1765
Difference	+ 1	− 7	+ 6	+ 2	− 15	− 10	+ 28	0	0	+ 1
Bashforth	—	1701	1730	—	1489	1501	1628	1629	1596	—
Boulengé	1622	1702	—	—	—	—	1565	—	—	—
Difference		+ 1					− 61			

Complaints were made of the strange vagaries of the instruments during some of these experiments. Now the Bashforth Chronograph requires only one short galvanic circuit passing through the clock and chronograph, and one long circuit passing through all the screens, and no difficulty of the nature complained of has been experienced before. But the use of the two Le Boulengé instruments brought in four additional galvanic currents. The disturbance in the instruments must therefore have arisen from induced currents caused by the conducting wires having somewhere been too near together.

In the former experiments the value of b' was given in tables under the form $2000\, b' \frac{w}{d^3}$, but it has since been found more convenient to express it under the form $K_v = 2b' \frac{w}{d^3} \times (1000)^2$. Thus the employment of many useless decimal places is avoided, while the same significant digits are retained. The method of finding b' has been fully explained at pages 56 to 60 of the published Reports.

The values of b' obtained from the experiments of 1867–8, have been combined, as far as possible, with those of 1878–9.

All particulars respecting each round have been stated in Tables I and II.

In Tables III, V, VII and IX the values of K_v obtained from each round have been arranged under their proper velocity v; and from these the mean values of K_v have been obtained.

These mean values of K_v were then plotted, and corrections were applied, which were afterwards further adjusted by differencing. These results are given in Tables IV, VI, VIII and X.

Every possible assistance was given at Shoeburyness. Captain O'Callaghan, R.A., Assistant Superintendent of Experiments, or Captain White, R.A., then Second Assistant, took charge of the gun and screens. And Captain C. Jones, R.A., then Second Officer in the Experimental Branch of the Director of Artillery's Department, Captain Morley, R.A., Proof Officer, R.G.F., and Captain McClintock, R.A., Secretary to the Sub-Committee on Iron Plates, took charge of the chronograph, and read off the records, which were then sent to me for reduction. The experiments appear to have been carried out very carefully and successfully. The results with high velocities are quite conclusive. But the results with low velocities are not quite so satisfactory, because the rounds fired were not sufficiently numerous, and because the shot frequently passed through the screens without breaking a thread.

If further experiments with low velocities were to be undertaken, it would be advisable to place (1) from six to eight screens near the gun, at intervals of 37½ feet, in order to secure correct muzzle velocities; and (2) two canvas screens to secure the exact initial directions of the shot. Distant screens would have to be used to obtain the exact times of flight over known spaces.

The following is a copy of the Shoeburyness Meteorological Register for the days of experimenting:—

		Barometer.	Thermometer.	
			Wet.	Dry.
		inches.	Degrees F.	Degrees F.
1878.	September 13 ..	30·10	51	56
„	„ 25 ..	29·65	46	50
„	„ 26 ..	29·90	41	49
„	„ 27 ..	30·05	42	49
„	October 31 ..	29·80	37	38
„	November 1 ..	29·85	41	42
„	December 4 ..	30·15	35	37
„	„ 5 ..	30·05	33	35
1879.	March 5 ..	30·05	45	46
„	„ 6 ..	30·15	42	46
„	„ 7 ..	29·95	37	39
„	„ 10 ..	30·40	41	42
„	„ 11 ..	30·25	42	45
„	„ 12 ..	29·40	40	43

In the reduction of the experiments of 1867–68, the weight of a cubic foot of air was taken to be 530·6 grs., but these experiments have been reduced on the supposition that it weighs 534·22 grs., which is the weight of a cubic foot of dry air at 62° F. under a pressure of 30 inches of mercury. The old coefficients have therefore been increased in the ratio of 530·6 to 534·22, or, as 1 to 1·0068, or, they are increased by about the 2-300ths of their former value.

I have the honor to be,
SIR,
Your obedient Servant,
FRANCIS BASHFORTH,

Late Professor of Applied Mathematics to the Advanced Class, and Referee to the Late Ordnance Select Committee.

To Major-General F. A. Campbell, R.A., C.B.,
Director of Artillery and Stores,
Woolwich.

Report VIII.—Table I

Showing the Times of the Shot passing through the Screens.

(Shot with Ogival Heads).

Date of Experiment.	Weight of Shot = w.	Diameter of Shot = d.	Weight of Charge.	Number of Round.	Screens 75 feet apart.														
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1878	lbs.	inches	lbs. oz.		"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
September 13	6·50	2·97	0 12	412	0·0000	0·0715	0·1438	0·2171	0·2912	0·3661	0·4418	0·5180	0·5950	0·6725	0·7505	0·8289	0·9077	0·9869	1·0664	1·1461
"	6·50	"	0 12	413	0·0000	0·0696	0·1399	0·2108	0·2825	0·3548	0·4277	0·5011	0·5751	0·6495	0·7245	0·7999	0·8759	0·9524	1·0293	1·1067
"	6·50	"	0 12	414	0·0000	0·0718	0·1442	0·2174	0·2912	0·3657	0·4407	0·5164	0·5925	0·6691	0·7462	0·8238	0·9019	0·9805	1·0596	
September 25	6·50	"	0 10	415	0·0000	0·0781	0·1569	0·2363	0·3163	0·3969	0·4780	0·5597	0·6420	0·7250	0·8086	0·8928	0·9777	1·0633	1·1496	
"	6·56	"	0 10	416	0·0000	0·0760	0·1523	0·2289	0·3059	0·3832	0·4610	0·5393	0·6180	0·6973	0·7770	0·8573	0·9381	1·0196	1·1017	1·1844
"	6·50	"	0 10	417	0·0000	0·0759	0·1523	0·2292	0·3066	0·3844	0·4629	0·5417	0·6212	0·7012	0·7818	0·8630	0·9449	1·0275	1·1109	1·1950
"	6·44	"	0 10	418	0·0000	0·0788	0·1583	0·2384	0·3191	0·4005	0·4827	0·5656	0·6493	0·7335	0·8185	0·9040				
"	6·50	"	0 10	419	0·0000	0·0777	0·1557	0·2343	0·3132	0·3926	0·4725	0·5528	0·6336	0·7150	0·7969	0·8795	0·9627	1·0465	1·1309	
"	6·50	"	0 8	420	0·0000	0·0808	0·1636	0·2451	0·3285	0·4136	0·4979	0·5836								
"	6·47	"	0 8	421	0·0000	0·0831	0·1663	0·2496	0·3332	0·4171	0·5014	0·5862	0·6715	0·7574	0·8439	0·9312	1·0192	1·1082	1·1990	
"	6·56	"	0 8	422	0·0000	0·0817	0·1642	0·2473	0·3312	0·4157	0·5009	0·5866	0·6729	0·7596	0·8468	0·9342	1·0219	1·1099	1·1979	
"	6·47	"	0 8	423	0·0000	0·0847	0·1697	0·2549	0·3406	0·4265	0·5128	0·5994	0·6865	0·7740	0·8620	0·9506	1·0396	1·1292		
September 26	6·66	"	0 8	424	0·0000	0·0967	0·1942	0·2919	0·3905	0·4897	0·5896	0·6899	0·7909	0·8924	0·9945	1·0971	1·2003	1·3041	1·4084	1·5133
"	6·56	"	0 8	425	0·0000	0·0943	0·1890	0·2842	0·3800	0·4762	0·5730	0·6704	0·7685	0·8672	0·9666	1·0667	1·1676	1·2692	1·3716	1·4749
"	6·63	"	0 8	426	0·0000	0·1028	0·2067	0·3096	0·4138	0·5187	0·6242	0·7304	0·8372	0·9447	1·0530	1·1622	1·2722	1·3831	1·4950	1·6079
"	6·47	"	0 6	427	0·0000	0·0929	0·1846	0·2776	0·3711	0·4650	0·5595	0·6544	0·7499	0·8459	0·9425	1·0398				
"	6·63	"	0 6	428	0·0000	0·0943	0·1891	0·2845	0·3803	0·4766	0·5734	0·6707	0·7685	0·8671	0·9660	1·0655	1·1655	1·2661	1·3672	1·4689
"	6·47	"	0 8	429	0·0000	0·0850	0·1706	0·2562	0·3430	0·4300	0·5175	0·6056	0·6943	0·7836	0·8735	0·9639	1·0550	1·1466	1·2389	
"	6·47	"	0 8	430	0·0000	0·0879	0·1763	0·2651	0·3545	0·4442	0·5345	0·6252	0·7163	0·8079	0·9000	0·9925	1·0854	1·1788	1·2728	1·3672
September 27	6·50	"	0 4	431	0·0000	0·0998	0·2009	0·3030	0·4060	0·5096										
"	6·63	"	0 4	432	0·0000	0·1049	0·2102	0·3169	0·4222	0·5288	0·6363	0·7442	0·8527							
"	6·56	"	0 4	433	0·0000	0·1067	0·2122	0·3194	0·4274	0·5361	0·6456	0·7558	0·8667	0·9784	1·0909	1·2039	1·3178	1·4324	1·5477	
"	6·63	"	0 4	434	0·0000	0·1021	0·2050	0·3088	0·4129	0·5180	0·6238	0·7302	0·8374	0·9452	1·0538	1·1630	1·2728	1·3834	1·4946	
"	6·56	"	0 4	435	0·0000	0·1024	0·2056	0·3096	0·4144	0·5200	0·6264	0·7336	0·8416	0·9505	1·0601	1·1706	1·2817	1·3937	1·5065	1·6200