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U. S. NAVAL INSTITUTE, ANNAPOLIS, MD.

THE LE DUC BALLISTIC FORMULÆ.

By G. W. PATTERSON.

The use of these formulæ, in the form given by Professor Alger in the NAVAL INSTITUTE PROCEEDINGS, Vol. 37, No. 2, Whole No. 138, has been limited to pressure calculations, and to fixing charges for low velocities when the charge for a higher velocity in the same gun was known.

As stated by Alger, they failed entirely when used to predict the performance of a powder in one gun from results obtained by firing the same powder in a gun of different caliber. As it was evident that this failure was due to the empirical values given the constants in the formulæ, it was decided to determine these values from actual data on the proving ground.

Starting with the basic formulæ:

$$v = \frac{au}{b+u},$$

$$a = a\Delta^{\frac{1}{x}} \left(\frac{w}{p} \right)^{\frac{1}{y}},$$

$$b = \beta \left(1 - \frac{\Delta}{\delta} \right) \frac{S^x}{p^y},$$

the values to be determined are those for a , the exponent x or variation due to chamber capacity, and the exponent y or variation due to weight of shell.

EXPERIMENT NO. 1. *Determination of a.*

A series of 5-inch 40-caliber guns was prepared, having the same chamber capacity, but with different lengths of travel of projectile, as shown on Plate 1. Provision was made for inserting pressure gauges at different points along the bore. Using the same powder charge, and the same weight of shell, the results shown on p. 887 were obtained.

	Charge	Muzzle velocity, f. s.	Maximum pressure, tons
Gun No. 127	8.8	2204	14.27
Gun No. 127	8.8	2204	14.67
Gun No. 127	8.8	2204	14.40
Gun No. 77	8.8	2162	14.16
Gun No. 77	8.8	2162	15.3
Gun No. 77	8.8	2162	13.81
Gun No. 68	8.8	2089	15.16
Gun No. 68	8.8	2089	15.51
Gun No. 68	8.8	2089	15.09
Gun No. 68	8.8	2089	14.88
Gun No. 72	8.8	1969	13.48
Gun No. 72	8.8	1964	13.55
Gun No. 72	8.8	1969	13.74
Gun No. 72	8.8	1969	14.39
Gun No. 67	8.8	1821	14.16
Gun No. 67	8.8	1821	14.11
Gun No. 67	8.8	1821	14.25

The results obtained in bore pressure gauges are plotted on Plate 2. From the basic formulæ we find by elimination:

$$a = \frac{vv'}{\Delta^{\frac{1}{x}} \left(\frac{u}{p} \right)^{\frac{1}{x}}} \cdot \frac{(u-u')}{(v'u - vu')}$$

From the above results, $a = \begin{cases} 6820 \text{ for No. 77,} \\ 6816 \text{ for No. 68,} \\ 6834 \text{ for No. 72,} \\ 6733 \text{ for No. 67.} \end{cases}$

As little hope had been entertained of obtaining good results with the shortest gun, the fourth result was discarded and the average value 6823 was adopted for use in future work.

EXPERIMENT NO. 2. Determination of exponent x , variation due to chamber capacity.

Using a fixed powder charge and the same weight of shell, rounds were fired in the 4-inch 40-Mk. VI and 4-inch 50-Mk. VII guns as follows:

71 P 4 Buz
 # 700 5-25-12
 Scale 1/2" = 1' 500
 3-40 CAL #222 GUN #1=13982' 5=657.84 mm
 Supersedes NO-675
 3-40 CAL CUP-OP GUNS: GUN NO. 68, Mk. II, Mod. 41; No. 67, Mk. II, Mod. 41; No. 72, Mk. IV; No. 77, Mk. IV.
 20-40-60-80-100-120-140-160-180-200-220-240-260-280-300-320-340-360-380-400-420-440-460-480-500-520-540-560-580-600-620-640-660-680-700-720-740-760-780-800-820-840-860-880-900-920-940-960-980-1000-1020-1040-1060-1080-1100-1120-1140-1160-1180-1200-1220-1240-1260-1280-1300-1320-1340-1360-1380-1400-1420-1440-1460-1480-1500-1520-1540-1560-1580-1600-1620-1640-1660-1680-1700-1720-1740-1760-1780-1800-1820-1840-1860-1880-1900-1920-1940-1960-1980-2000-2020-2040-2060-2080-2100-2120-2140-2160-2180-2200-2220-2240-2260-2280-2300-2320-2340-2360-2380-2400-2420-2440-2460-2480-2500-2520-2540-2560-2580-2600-2620-2640-2660-2680-2700-2720-2740-2760-2780-2800-2820-2840-2860-2880-2900-2920-2940-2960-2980-3000-3020-3040-3060-3080-3100-3120-3140-3160-3180-3200-3220-3240-3260-3280-3300-3320-3340-3360-3380-3400-3420-3440-3460-3480-3500-3520-3540-3560-3580-3600-3620-3640-3660-3680-3700-3720-3740-3760-3780-3800-3820-3840-3860-3880-3900-3920-3940-3960-3980-4000-4020-4040-4060-4080-4100-4120-4140-4160-4180-4200-4220-4240-4260-4280-4300-4320-4340-4360-4380-4400-4420-4440-4460-4480-4500-4520-4540-4560-4580-4600-4620-4640-4660-4680-4700-4720-4740-4760-4780-4800-4820-4840-4860-4880-4900-4920-4940-4960-4980-5000-5020-5040-5060-5080-5100-5120-5140-5160-5180-5200-5220-5240-5260-5280-5300-5320-5340-5360-5380-5400-5420-5440-5460-5480-5500-5520-5540-5560-5580-5600-5620-5640-5660-5680-5700-5720-5740-5760-5780-5800-5820-5840-5860-5880-5900-5920-5940-5960-5980-6000-6020-6040-6060-6080-6100-6120-6140-6160-6180-6200-6220-6240-6260-6280-6300-6320-6340-6360-6380-6400-6420-6440-6460-6480-6500-6520-6540-6560-6580-6600-6620-6640-6660-6680-6700-6720-6740-6760-6780-6800-6820-6840-6860-6880-6900-6920-6940-6960-6980-7000-7020-7040-7060-7080-7100-7120-7140-7160-7180-7200-7220-7240-7260-7280-7300-7320-7340-7360-7380-7400-7420-7440-7460-7480-7500-7520-7540-7560-7580-7600-7620-7640-7660-7680-7700-7720-7740-7760-7780-7800-7820-7840-7860-7880-7900-7920-7940-7960-7980-8000-8020-8040-8060-8080-8100-8120-8140-8160-8180-8200-8220-8240-8260-8280-8300-8320-8340-8360-8380-8400-8420-8440-8460-8480-8500-8520-8540-8560-8580-8600-8620-8640-8660-8680-8700-8720-8740-8760-8780-8800-8820-8840-8860-8880-8900-8920-8940-8960-8980-9000-9020-9040-9060-9080-9100-9120-9140-9160-9180-9200-9220-9240-9260-9280-9300-9320-9340-9360-9380-9400-9420-9440-9460-9480-9500-9520-9540-9560-9580-9600-9620-9640-9660-9680-9700-9720-9740-9760-9780-9800-9820-9840-9860-9880-9900-9920-9940-9960-9980-10000-10020-10040-10060-10080-10100-10120-10140-10160-10180-10200-10220-10240-10260-10280-10300-10320-10340-10360-10380-10400-10420-10440-10460-10480-10500-10520-10540-10560-10580-10600-10620-10640-10660-10680-10700-10720-10740-10760-10780-10800-10820-10840-10860-10880-10900-10920-10940-10960-10980-11000-11020-11040-11060-11080-11100-11120-11140-11160-11180-11200-11220-11240-11260-11280-11300-11320-11340-11360-11380-11400-11420-11440-11460-11480-11500-11520-11540-11560-11580-11600-11620-11640-11660-11680-11700-11720-11740-11760-11780-11800-11820-11840-11860-11880-11900-11920-11940-11960-11980-12000-12020-12040-12060-12080-12100-12120-12140-12160-12180-12200-12220-12240-12260-12280-12300-12320-12340-12360-12380-12400-12420-12440-12460-12480-12500-12520-12540-12560-12580-12600-12620-12640-12660-12680-12700-12720-12740-12760-12780-12800-12820-12840-12860-12880-12900-12920-12940-12960-12980-13000-13020-13040-13060-13080-13100-13120-13140-13160-13180-13200-13220-13240-13260-13280-13300-13320-13340-13360-13380-13400-13420-13440-13460-13480-13500-13520-13540-13560-13580-13600-13620-13640-13660-13680-13700-13720-13740-13760-13780-13800-13820-13840-13860-13880-13900-13920-13940-13960-13980-14000-14020-14040-14060-14080-14100-14120-14140-14160-14180-14200-14220-14240-14260-14280-14300-14320-14340-14360-14380-14400-14420-14440-14460-14480-14500-14520-14540-14560-14580-14600-14620-14640-14660-14680-14700-14720-14740-14760-14780-14800-14820-14840-14860-14880-14900-14920-14940-14960-14980-15000-15020-15040-15060-15080-15100-15120-15140-15160-15180-15200-15220-15240-15260-15280-15300-15320-15340-15360-15380-15400-15420-15440-15460-15480-15500-15520-15540-15560-15580-15600-15620-15640-15660-15680-15700-15720-15740-15760-15780-15800-15820-15840-15860-15880-15900-15920-15940-15960-15980-16000-16020-16040-16060-16080-16100-16120-16140-16160-16180-16200-16220-16240-16260-16280-16300-16320-16340-16360-16380-16400-16420-16440-16460-16480-16500-16520-16540-16560-16580-16600-16620-16640-16660-16680-16700-16720-16740-16760-16780-16800-16820-16840-16860-16880-16900-16920-16940-16960-16980-17000-17020-17040-17060-17080-17100-17120-17140-17160-17180-17200-17220-17240-17260-17280-17300-17320-17340-17360-17380-17400-17420-17440-17460-17480-17500-17520-17540-17560-17580-17600-17620-17640-17660-17680-17700-17720-17740-17760-17780-17800-17820-17840-17860-17880-17900-17920-17940-17960-17980-18000-18020-18040-18060-18080-18100-18120-18140-18160-18180-18200-18220-18240-18260-18280-18300-18320-18340-18360-18380-18400-18420-18440-18460-18480-18500-1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80-35200-35220-35240-35260-35280-35300-35320-35340-35360-35380-35400-35420-35440-35460-35480-35500-35520-35540-35560-35580-35600-35620-35640-35660-35680-35700-35720-35740-35760-35780-35800-35820-35840-35860-35880-35900-35920-35940-35960-35980-36000-36020-36040-36060-36080-36100-36120-36140-36160-36180-36200-36220-36240-36260-36280-36300-36320-36340-36360-36380-36400-36420-36440-36460-36480-36500-36520-36540-36560-36580-36600-36620-36640-36660-36680-36700-36720-36740-36760-36780-36800-36820-36840-36860-36880-36900-36920-36940-36960-36980-37000-37020-37040-37060-37080-37100-37120-37140-37160-37180-37200-37220-37240-37260-37280-37300-37320-37340-37360-37380-37400-37420-37440-37460-37480-37500-37520-37540-37560-37580-37600-37620-37640-37660-37680-37700-37

	Charge, lbs.	Muzzle velocity, f. s.	Maximum pressure, tons
4-inch 40-Mk. VI	5.5	2125	13.2
4-inch 40-Mk. VI	5.5	2125	13.34
4-inch 40-Mk. VI	5.5	2125	13.15
4-inch 50-Mk. VII	5.5	1846	6.87
4-inch 50-Mk. VII	5.5	1846	7.07
4-inch 50-Mk. VII	5.5	1846	7.08

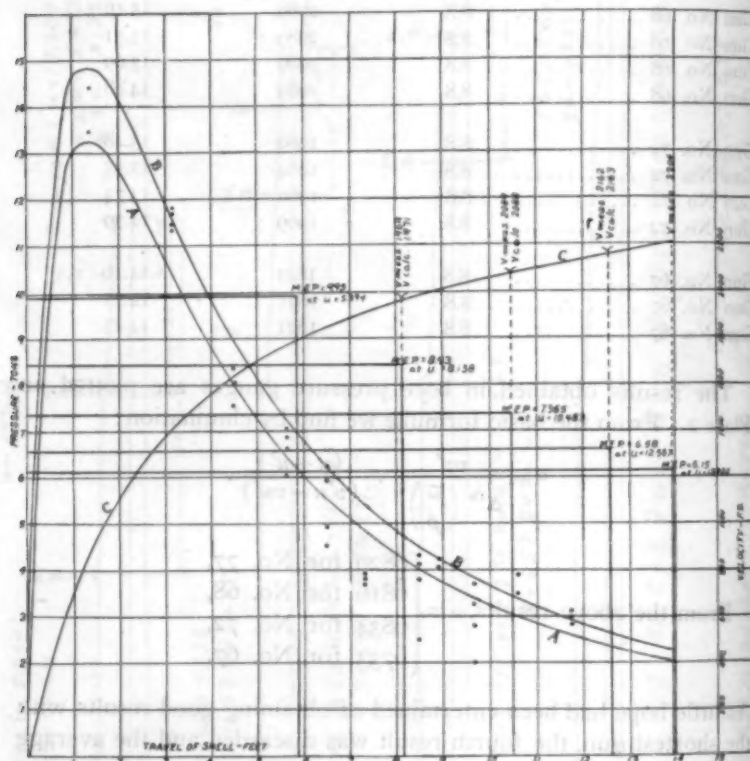


PLATE 2.—5-INCH 40-CAL. CUT-OFF GUN EXPERIMENT. DEC. 8, 1911.

From the basic formulæ we find:

$$\left(\frac{S'}{S}\right)^x = \frac{(a'-v')u'v}{(a-v)uv'} \cdot \frac{(\delta-\Delta)}{(\delta-\Delta')}.$$

From the above results, $x = .674$ and the value used for the formula is $\frac{2}{3}$.

EXPERIMENT NO. 3. *Determination of exponent y or variation due to weight of shell.*

Shell of the same type but of different weights were fired in the 5-inch 50-Mk. VI-1 gun, using a constant powder charge, with results as follows:

Charge, lbs.	Wt. of shells, lbs.	Muzzle veloc., f. s.	Max. pressure, tons
14	50	2437	9.77
14	50	2437	9.77
14	50	2437	9.77
14	50	2437	9.77
14	60	2291	10.61
14	60	2291	10.68
14	60	2291	10.47

From the basic formulæ we find:

$$\left(\frac{p}{p'}\right)^y = \frac{(a' - v')v}{(a - v)v'}.$$

From the above results, $y = .646$ and the value $\frac{2}{3}$ was adopted.

With the values found, we have for working formulæ:

$$v = \frac{au}{b + u},$$

$$a = 6823\Delta^{1/3} \left(\frac{\bar{w}}{p}\right)^{1/3},$$

$$b = \beta \left(1 - \frac{\Delta}{\delta}\right) \left(\frac{S}{p}\right)^{1/3},$$

$$P = \frac{a^2 b p u}{2240gA(b + u)^3},$$

in all of which:

$\bar{w}$ = weight of smokeless powder in pounds.

p = weight of projectile in pounds.

Δ = density of loading.

S = chamber capacity in cubic inches.

β = a powder constant.

v = muzzle velocity in f. s.

u = travel of projectile in feet.

A = cross-section of the bore in square inches.

g = acceleration of gravity in f. s.

δ = density of powder. In navy powder this varies practically with the quantity of total volatiles and is shown graphically on Plate 3.

P = effective pressure on base of shell in tons per square inch at any point u in travel of shell.

Plate 2 shows curve *A*, the effective pressure on the base of the shell computed from the velocity obtained in the long gun; curve *B*, the estimated pressure on the gun computed by adding 12 per cent to the pressure on the shell; curve *C*, the velocity curve calculated from the velocity found in the long gun, and the plotted velocities obtained in firing the cut-off guns; the mean effective pressure on the shell computed from the muzzle velocity of each gun; the plotted points of pressure by gauges in all guns.

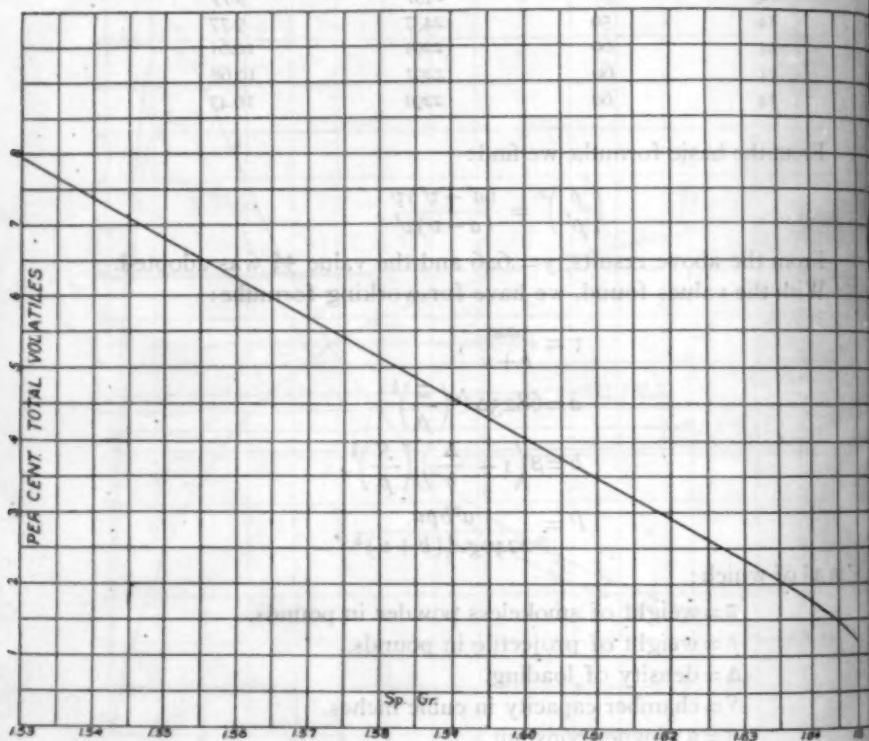


PLATE 3.—SPECIFIC GRAVITY OF NAVY POWDER. WATER AT 4° C.

$$\text{Sp. gr.} = \frac{12.3728 - .132 \text{ T. V.}}{7.4}$$

Plotted on a large scale, the space-pressure curve was measured with a planimeter for each gun. In all cases, except in the shortest gun, these measurements were found to agree, within two-tenths of 1 per cent, with the muzzle energy calculated from the actual velocity found in each gun.

base of the
gun; curve
ding 12 per
curve calcu-
the plotted
an effective
city of each
s.



AT 4° C.

as measured
the shortest
two-tenths
in the actual



5"-40
No. 127

5"-40
No. 72

5"-40
No. 67

5"-40
No. 77

5"-40
No. 68

GUNS USED IN EXPERIMENT NO. I.

The results obtained by the bore-pressure gauges are so erratic in most cases that comparison is difficult. The results plotted are from the full compression of the discs and it can be stated that this is a fair average of what has always been obtained on the proving ground. In general, it appears that for this type of rifling and shell band a factor of 12 per cent above the shell pressure is a safe figure for calculating gun pressures.

When these formulæ are applied to the performance of the same powder in different guns it is found that they show remarkably close agreement between calculated and measured velocities when the powder charge is entirely consumed in the gun. The following table shows such results, calculations having been made by the original Le Duc formulæ and by the Le Duc formulæ with new constants.

Powder		Gun	Velocity	Velocity calc. from average β	
				Le Duc Old style	Le Duc New Style
IHL	1	6-inch 50 VIII-2.....	2660	2689	2664
IHL	1	6-inch 40 III.....	2203	2161	2205
IHL	1	5-inch 50 V.....	2685	2724	2678
LRFD	2	12-inch Mk. VII	2900	2907	2910
LRFD	2	12-inch Mk. VI	2850	2840	2939
IHPB	12	5-inch 50-Mk. V	2350	2376	2345
IHPB	12	5-inch 40-Mk. III.....	2200	2175	2203
IHX	1	13-inch 35 No. 34.....	2000	1965	2007
IHX	1	7-inch 45-Mk. I	2700	2752	2710
IHX	1	8-inch 45-Mk. VI	2600	2611	2595
ISPB	3	4-inch 50 VII	2500	2406	2499
ISPB	3	3-inch 50 VI.....	2700	2782	2700

The formulæ in the present state give as good results as the modified Sarrau formula. In using them the conditions of firing must be accurately known and the powder must all be consumed in the gun. If the powder is not all consumed, a false value of β is obtained and the pressure curve will not represent properly the work of the powder in the gun.