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Temperature Compensated Loading Curves for the 7.62 x 54R Armor Piercing Incendiary (API) Round

by
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OCTOBER 2009

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FOREWORD

This report describes the results of testing conducted during the period of 31 January through 1 February 2009 at the Weapons Survivability Laboratory (WSL), Naval Air Warfare Center Weapons Division (NAWCWD), China Lake, California. The purpose of this testing was to learn which variables were statistically significant in controlling the velocity of the 7.62 x 54R API round. This report was prepared for the timely presentation of this information, and is released at the working level. This document was reviewed for technical accuracy by Mr. Joseph Manchor (Code 418300D).

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14. ABSTRACT

(U) This report documents the effort to determine what variables are statistically significant in determining the velocity of the 7.62-millimeter X 54R armor piercing incendiary (API) round. The Design of Experiments approach to testing was used for this study. After the determination of the statistically significant variables is made, loading curves are generated taking into account these variables to achieve the desired velocity. The knowledge gained from this study will provide Weapons Survivability Laboratory (WSL) firing officers with the ability to shoot the 7.62 x 54R with accuracy in velocity and repeatability from shot-to-shot.

15. SUBJECT TERMS
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INTRODUCTION

BACKGROUND

Over the past 25 years, there have been occasional notable inconsistencies in desired velocity of different rounds fired for testing at the Weapons Survivability Laboratory (WSL) of the Naval Air Warfare Center Weapons Division (NAWCWD), China Lake, California. These occurrences have generated much speculation as to what caused the "failure," without a systematic approach ever being taken to determine the controlling factors for velocity. Most recently, the velocity of the 7.62-millimeter (mm) x 54R round (see Figure 1) fired at the WSL has had limited success in satisfying the customer requirement for holding the impact velocity to within ±50 feet per second (ft/s) of the desired velocity. This is supported by statistical analysis of 72 shots conducted prior to this effort.

FIGURE 1. Cartridge, Bullet, Penetrator, and Headstamp
of the 7.62-Millimeter x 54R Used in This Effort.

Data from 72 shots was analyzed and the results are presented in Table 1.

TABLE 1. Statistical Analysis of Velocity Data.

Mean	2610.636
Standard Error	3.2462[illegible]
Median	2609.634
Mode	2616.535
Standard Deviation	27.5450[illegible]
Sample Variance	758.7291
Kurtosis	0.5715[illegible]
Skewness	-0.1387[illegible]
Range	141.38
Minimum	2545.473
Maximum	2686.853
Sum	187965.8
Count	72

The requirement is for 2,600 ft/s ±50 ft/s. The actual data, as can be seen from Table 1, is 2,610.636 ft/s ±**76.22** ft/s. Out of these 72 shots **six** were outside the acceptable range.

A histogram of the 72 test velocities measured before this effort was undertaken is shown in Figure 2.

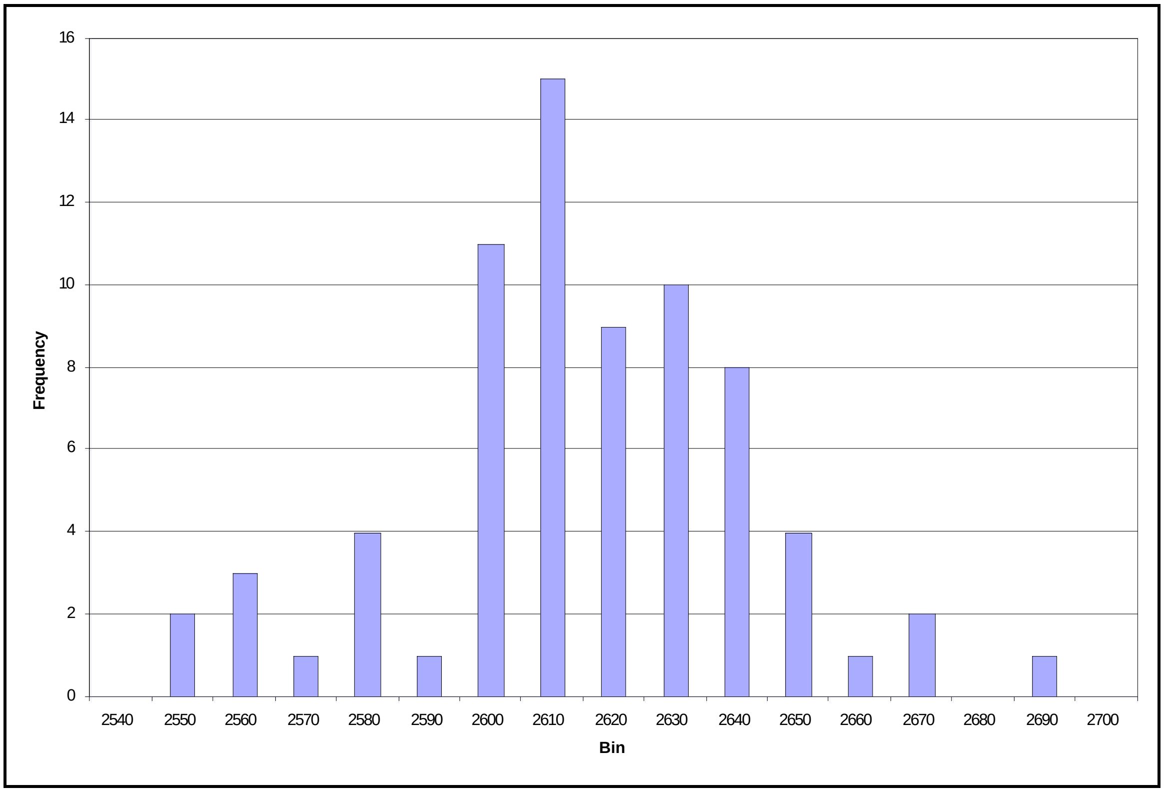

FIGURE 2. Histogram of 72 Test Velocities Measured Before This Effort.

The loading curves generated and used by WSL for a number of years have taken into consideration the variability in mass of the bullets, but this has not been enough to account for the variability in velocity.

OBJECTIVE

The two main objectives of this study were as follows:

1. To learn which variables were important to controlling the velocity of the 7.62 mm x 54R round.
2. To generate a loading curve, taking into consideration all the statistically significant variables enabling us to meet the requirement of ±50 ft/s of the desired velocity.

APPROACH

Preliminary Review

The author carefully reviewed the existing WSL process for controlling the velocity and postulated that the variables affecting bullet velocity are as follows:

Powder Amount. The amount of powder used in the case of a cartridge is typically the parameter that is controlled for determining the velocity of a bullet for the hobby handloader and the commercial production of cartridges. Accuracy in the measurement of powder when handloading is important. WSL firing officers used a scale capable of measuring mass to one hundredth of a grain (gr).

Bullet Mass. The variability of bullet mass in manufactured bullets is not great but may cause an effect upon bullet velocity. In a sample of 204 bullets, the mass of each bullet varied slightly (204 bullets; maximum = 163.98 gr, minimum = 158.02 gr).

Case Volume. The case volume is mainly determined by physical dimensions of the interior of the case during manufacturing (i.e., a parameter that is difficult to measure and beyond the control of the WSL firing officers). Case volume is also affected by the depth of the seating of the bullet. The firing officers used a bullet press to consistently control the seat height.

Temperature. WSL is an outdoor laboratory. On any day of the year the change in temperature fluctuates as much as 40 degrees. The heat load generated by direct sunlight on the gun directly contributes to the change in temperature. While ambient temperature is important, the temperature of concern and that will be controlled for this testing is more accurately described as soak temperature—powder, case, barrel, and breach temperature at equilibrium. The burning of modern smokeless gunpowder is a chemical process. Chemical processes are affected by temperature, the higher the temperature the faster the reaction. Temperature can also affect the bore diameter and bullet diameter and, therefore the friction associated with the bullet engaging the rifling and passing through the barrel. The approach taken in this testing will not differentiate between these effects.

Primer Condition. Primers are used to ignite the gunpowder but add a significant amount of energy to the combustion process involved in firing a bullet. The cases used by WSL are foreign made and are Berdan-primed, which does not allow for removing the primer and replacing it with one of known pedigree. This limits the firing officer's control of this variable. It has been noted infrequently that primers are faulty and do not ignite the gunpowder (misfires). Subsequent inspections of these primers have on occasion revealed that there is corrosion present in the bottom of the case where the primer flash holes are located. The exact corrosion products and source have not been investigated. The cases used in this investigation will be inspected for corrosion prior to use. No case with evidence of corrosion will be used.

Barrel Condition. The amount of control over this parameter is questionable. Certainly, the barrel could be cleaned prior to each shot; however, the opinions about the effect are debatable. Some precision shooters clean their barrels after each shot. Others, notably competitive target shooters, always shoot a first shot not for the record because it is always a "flier" (not consistent impact point for the same sight picture as subsequent shots).

Compression of Powder. If the volume of the powder being used is large enough to fill the majority of the case, when the bullet is seated it will compress the powder. This will cause the cylindrical grains of the rifle powder to fracture, changing the burn rate of the powder. This could cause erratic velocity results.

The approach taken to control the velocity for our testing was to make use of the two-level factorial design of experiments approach to determining which variables are statistically significant. A two-level factorial design has only two levels of each variable being studied and all possible combinations of the two levels for each of the variables are run as tests. For more information on the design of experiments, see Reference 1.

The author purports that the four independent variables (i.e., ones that can be controlled) are as follows.

1. Powder amount (q)
2. Bullet mass (m)
3. Temperature (T)
4. Barrel condition (c)

Given these independent variables, the two-level factorial design test approach is delineated in Table 2. The "+" sign indicates the high option of the variable and "-" indicates the low option of the variable.

All possible combinations of the variables are systematically listed. This order of runs is called the Yates order.

TABLE 2. Two-Level Factorial Test Design with 2^4 Variables.

Run	Bullet mass	Powder	Temperature	Barrel
1	-	-	-	-
2	+	-	-	-
3	-	+	-	-
4	+	+	-	-
5	-	-	+	-
6	+	-	+	-
7	-	+	+	-
8	+	+	+	-
9	-	-	-	+
10	+	-	-	+
11	-	+	-	+
12	+	+	-	+
13	-	-	+	+
14	+	-	+	+
15	-	+	+	+
16	+	+	+	+

Powder Amount (q). It was brought to the author's attention that the powder used for down loading the rounds (IMR 4350) took a high volume of the case. Upon further questioning, it was stated that seating the bullet was probably compressing the powder. Compressing the powder could cause the grains of powder to fracture, changing the burn rate of the powder. This might have caused some of the erratic velocity results. It was recommended that for this testing, and all future downloading using the 7.62mm x 54R round, a change in powder type would be advantageous. Upon investigating the properties of rifle powders that were available, IMR 4895 was chosen. IMR 4895 is a faster burning powder that requires less volume for the same velocity than IMR 4350. WSL did not have experience using this new powder, so as a starting point, a loading curve downloaded from the web (www.reloadersnest.com) (Reference 2) was used (see Figure 3). The loading curves presented on reloadersnest.com had a curve for 165 gr 7.62mm x 54R bullets. This loading curve was used because it was closest to what WSL was shooting.

Two loads were used corresponding to the high and low for the "two-level factorial design of experiments" process implemented for this investigation. The low value for powder load was selected from the curve for a predicted velocity of 2,500 ft/s; 100 ft/s below the target velocity of 2,600 ft/s and the high value for powder load was selected from the curve for the predicted velocity of 2,700 ft/s.

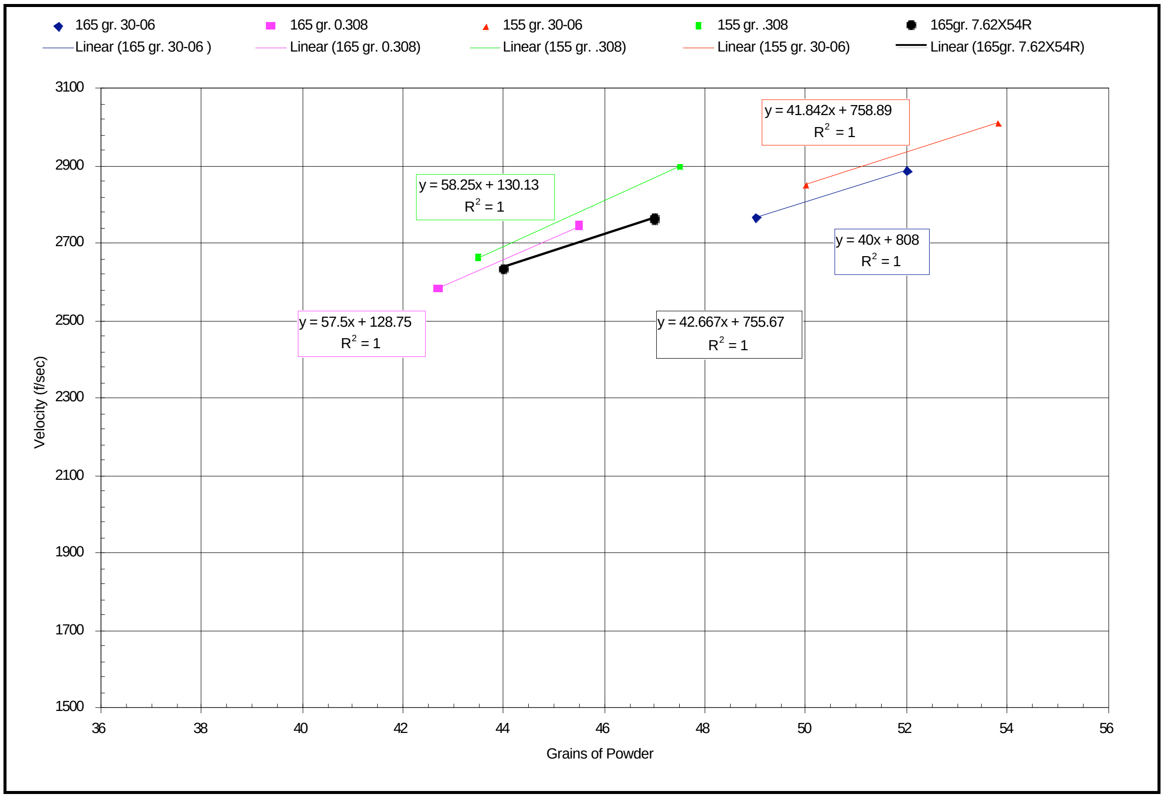

FIGURE 3. Loading Curves for .30 cal/7.62mm x 54R Bullets Using IMR 4895 Powder (Reference 2).

Bullet Mass (m). The mass of 100 bullets was measured and an average and standard deviation were calculated. After inspection of the bullet masses the bullet mass high value variable used bullets that were at least 1.35 standard deviations heavier than the average (the heaviest bullet was not used) and the bullet mass low variable used bullets that were at least 1.35 standard deviations lighter than the average (the lightest two bullets were not used).

Temperature (T). The two temperatures were arbitrarily selected. The low variable of 32ºF and the high temperature variable of 100ºF were selected.

The low temperature was achieved by circulating cold gas past the Mann gun barrel. The source of the cold gas was dry ice. Figure 4 shows the un-insulated duct work used to circulate cold gas over the barrel. The circulation fans were installed in the lid of the ice cooler in which the dry ice was placed.

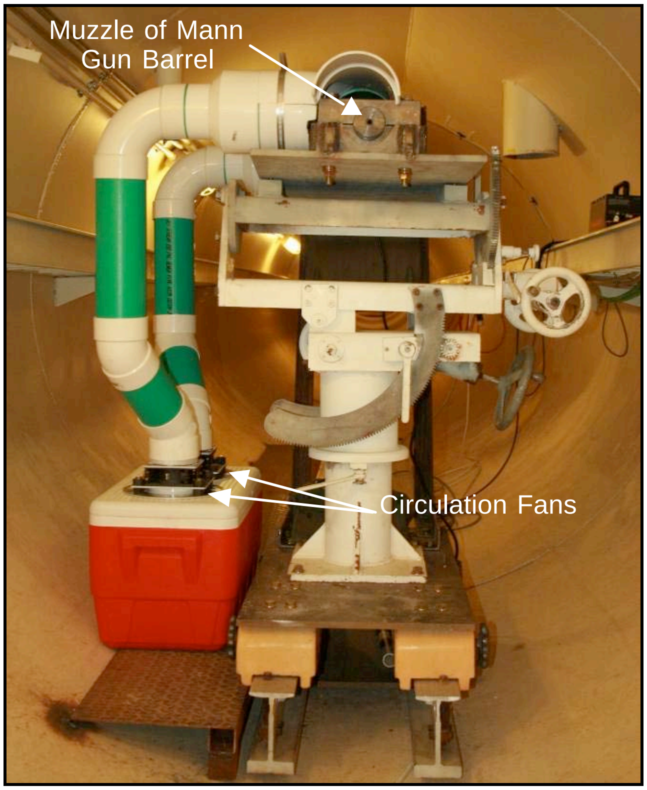

FIGURE 4. Setup for Chilling Barrel to 32ºF.

The high temperature was achieved by energizing heat tape that was wrapped around the gun barrel. Figure 5 shows the breach end of the Mann gun barrel with the tag end of the heat tape visible.

A controller was used to achieve the set points for testing whether the barrel was being heated or cooled. Figure 6 shows the controller and temperature read-out used in testing. A thermocouple was inserted into the breach of the barrel. It was used to verify that the temperature set point was being controlled. The read out of the thermocouple inserted in the breach was displayed on the digital multimeter.

Figure 7 shows the fully insulated and instrumented Mann gun barrel ready for testing.

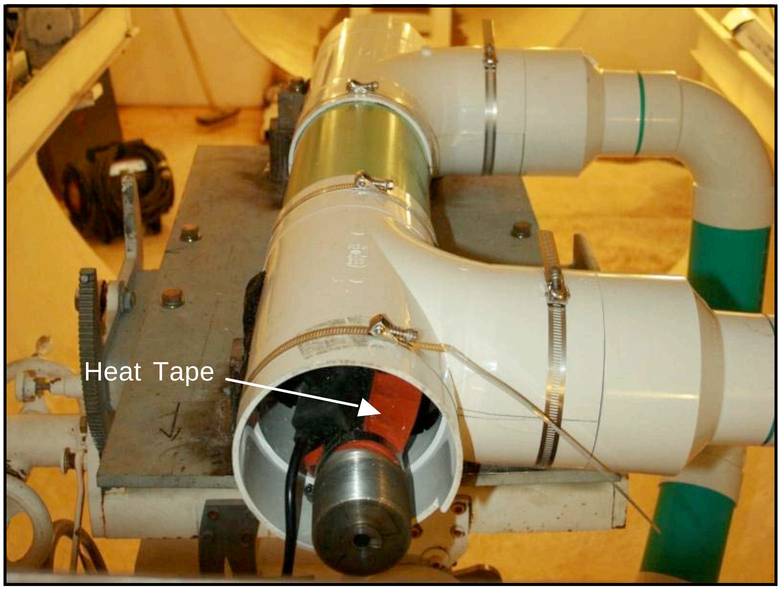

FIGURE 5. Tag End of Heat Tape Wrapped Around the Barrel.

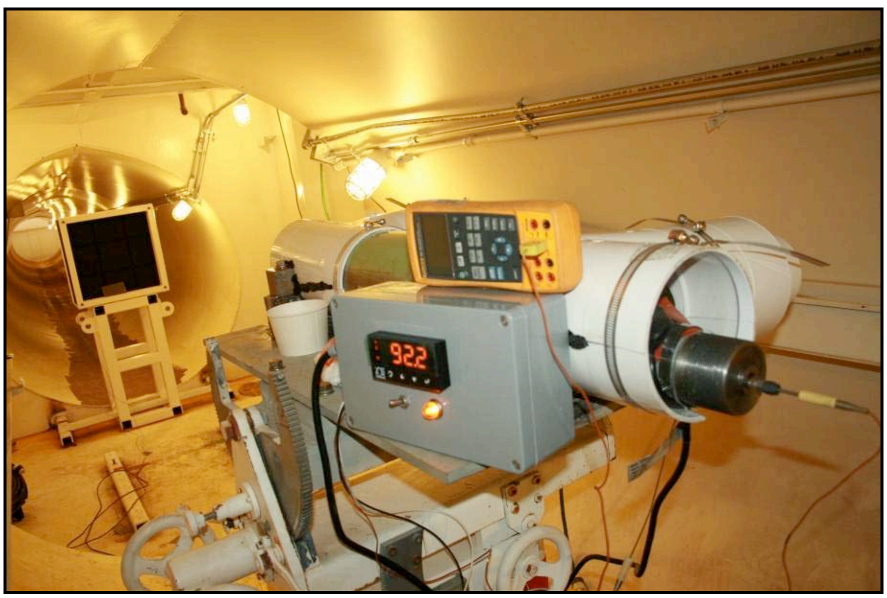

FIGURE 6. Controller Used to Achieve Hot and Cold Set Points.

FIGURE 7. Mann Gun Barrel Ready for Testing.

The breach block screws onto the breach end of the Mann barrel. It houses the firing pin and solenoid for remotely firing the round. The breach block is made from steel and has high thermal mass. The breach block and round were conditioned for the 100-degree tests using an environmental oven. For the 32-degree tests, the breach block and round were sealed in a plastic bag and stored in a thermally insulated container with ice (at 32ºF) prior to testing. This was necessary to prevent the breach block from acting as a thermal sink by altering the temperature of the conditioned barrel.

Barrel Condition (c). The barrel condition is a discrete variable, over which there is not much control. The barrel was either cleaned immediately before the shot or it was not. As a result, depending on the random selection of shot order, more than one shot was fired consecutively from a dirty barrel. A synopsis of the high and low options defined for each variable is listed in Table 3.

TABLE 3. Low and High Options for the Test Variables.

Condition	+	-
Bullet mass (m)	>162.452 gr	<160.603 gr
Powder amount (q)	45.57 gr	40.88 gr
Temperature (T)	100ºF	32ºF
Barrel condition (c)	Cleaned immediately before shot	Not cleaned immediately before shot

The dependent variable in this series of tests is Velocity (V). The lurking variables (i.e., uncontrollable variables) are at a minimum:

1. Case volume
2. Primer condition
3. Unknown

METHODS AND CONDITIONS

The test setup is shown in Figure 8. Velocity, the dependent variable, was calculated by measuring the time of travel of the bullet over a known distance. Breaking a piece of graphite at the muzzle of the barrel was the start time, and penetrating a piece of break paper placed on the front of the bullet trap was the stop time.

The conditions chosen for testing were dictated by the high and low conditions of the independent variables.

FIGURE 8. Test Setup.

So that bias was not introduced into the test results, the standard or Yates order of tests listed in Table 2 was randomized. Table 4 presents the random order of the tests as they were conducted.

Four center point tests were conducted. Center points are valuable because they provide an estimate of error against which effects can be measured and they provide a test on the model. Center points allow us to check for curvature by seeing if there is a significant difference between the center point average and the average of the factorial points. They also allow for a test of repeatability. The center point independent variable values and their placement in the test order are also shown in Table 4.

TABLE 4. Random Order of Tests and Conditions.

Test	Yates no.	Bullet no.	Bullet mass (m), gr	Powder (q), gr	Temperature (T), ºF	Barrel (c)
1	16	95	162.64	45.57	100	Clean
2	7	53	160.06	45.57	100	
3	11	67	160.22	45.57	32	Clean
4	6	31	162.54	40.88	100	
5	10	64	162.48	40.88	32	Clean
CP1		7	161.54	43.23	Ambient	Clean
6	13	98	160.24	40.88	100	Clean
7	1	33	160.54	40.88	32	
8	4	23	162.64	45.57	32	
CP2		63	161.54	43.23	Ambient	Clean
9	9	54	160.60	40.88	32	Clean
CP3		73	161.52	43.23	Ambient	Clean
10	14	90	162.58	40.88	100	Clean
11	8	49	162.64	45.57	100	
12	2	18	162.72	40.88	32	
13	12	71	162.98	45.57	32	Clean
14	5	52	160.34	40.88	100	
15	3	44	160.42	45.57	32	
CP4		80	161.54	43.23	Ambient	Clean
16	15	100	160.54	45.57	100	Clean

TEST RESULTS AND STATISTICAL ANALYSIS

The temperatures listed in Table 4 were target temperatures and the temperatures listed in Table 5 are measured temperatures. The test was conducted and the results are tabulated in Table 5.

TABLE 5. Test Results.

Test	Barrel temp., ºF	Bore temp., ºF	Distance, in.	Time, s	Velocity, ft/s
1	94.4	101.3	156.5	0.004750	2745.61
2	95.4	102.7	156.5	0.004700	2774.82
3	28.5	33.6	156.3	0.004913	2651.13
4	101.2	98.3	156.3	0.005231	2489.96
5	31.9	36.0	156.3	0.005581	2333.81
CP1	75.9	78.3	156.3	0.005063	2572.59
6	102.3	99.6	156.3	0.005194	2507.70
7	29.5	34.2	156.4	0.005451	2391.00
8	29.4	33.2	156.3	0.004945	2633.97
CP2	74.4	73.4	155.5	0.014844	872.97
9	29.9	34.6	155.2	0.005510	2347.25
CP3	73.6	77.9	155.2	0.005028	2572.26
10	101.4	107.5	155.1	0.005253	2460.50
11	101.4	105.0	155.2	0.004726	2736.63
12	31.4	30.2	155.0	0.005375	2403.10
13	31.4	29.7	155.1	0.004960	2605.85
14	104.6	106.5	155.1	0.005081	2543.79
15	29.3	28.7	155.1	0.004839	2599.03
CP4	76.9	81.6	155.2	0.004973	2600.71
16	101.9	102.9	155.1	0.004689	2756.45

A Microsoft Excel worksheet was created that performed the calculation of effects and interactions required for evaluating the data. The results are presented in Table 6.

TABLE 6. Calculations for Effects and Interactions.

Mass of Bullet = m, Amount of Powder = q, Temperature = T, Barrel Condition = c

Yates Order	Mean		m	q	T	c	m, q	m, T	m, c	q, T	q, c	T, c	m, q, T	m, q, c	m, T, c	q, T, c	m, q, T, c	Velocity	Data From Test: Time (s)	Data From Test: Dist (in)
1	1		-1	-1	-1	-1	1	1	1	1	1	1	-1	-1	-1	-1	1	2391.00	0.005451	156.4
2	1		1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	-1	-1	2403.10	0.005375	155.0
3	1		-1	1	-1	-1	-1	1	1	-1	-1	1	1	1	-1	1	-1	2599.03	0.004973	155.1
4	1		1	1	-1	-1	1	-1	-1	-1	-1	1	-1	-1	1	1	1	2633.97	0.004945	156.3
5	1		-1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	1	-1	2543.79	0.005081	155.1
6	1		1	-1	1	-1	-1	1	-1	-1	1	-1	-1	1	-1	1	1	2489.96	0.005231	156.3
7	1		-1	1	1	-1	-1	-1	1	1	-1	-1	-1	1	1	-1	1	2774.82	0.004700	156.5
8	1		1	1	1	-1	1	1	-1	1	-1	-1	1	-1	-1	-1	-1	2736.63	0.004726	155.2
9	1		-1	-1	-1	1	1	1	-1	1	-1	-1	-1	1	1	1	-1	2347.25	0.005510	155.2
10	1		1	-1	-1	1	-1	-1	1	1	-1	-1	1	-1	-1	1	1	2333.81	0.005581	156.3
11	1		-1	1	-1	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1	2651.13	0.004913	156.3
12	1		1	1	-1	1	1	-1	1	-1	1	-1	-1	1	-1	-1	-1	2605.85	0.004960	155.1
13	1		-1	-1	1	1	1	-1	-1	-1	-1	1	1	1	-1	-1	1	2507.70	0.005194	156.3
14	1		1	-1	1	1	-1	1	1	-1	-1	1	-1	-1	1	-1	-1	2460.50	0.005253	155.1
15	1		-1	1	1	1	-1	-1	-1	1	1	1	-1	-1	-1	1	-1	2756.45	0.004689	155.1
16	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2745.61	0.004750	156.5
	40980.62		-162	2026	1050	-164	43	-138	-71.8	-3.26	193	14.1	61	-34	140	-80.8	75.4			
Mean=	2561.289	Effects=	-20.2	253	131	-20.5	5.37	-17.3	-8.97	-0.41	24.1	1.77	7.63	-4.24	17.5	-10.1	9.43			
S.D.=	149.483	t_E=	-0.270	3.389	1.757	-0.274	0.072	-0.231	-0.120	-0.005	0.323	0.024	0.102	-0.057	0.234	-0.135	0.126			

Student t Statistic 15 DoF	
t*(90%)	1.753
t*(95%)	2.131
t*(99%)	2.947

Analysis of Curvature					
		1	2572.59	0.005063	156.3
		2*	872.97	0.014844	155.5
Curvature =	-20.56	3	2572.26	0.005028	155.2
t_c =	-0.22	4	2600.71	0.004973	155.2
		Center Point Average=	2581.85		

*center point 2 was thrown out, the result can't be explained or justified

An effect or interaction is statistically significant if "t_E" (the signal) is greater than the Student's t Statistic (t*) (the noise) for the confidence level required. There were 16 tests, so the number of degrees of freedom for this testing is 15 (number of tests minus 1). We select 90% confidence. By comparing t_c to t*(90), it can be concluded that there is no significant curvature to the data. The t_E values indicate that none of the 2-, 3-, or 4-way interactions are significant. **Therefore, the only statistically significant effects are powder, amount, and temperature.**

The development of a loading curve that takes temperature into account and adjusts the powder amount (since this is a controlled variable) to compensate for temperature variability during testing is the remaining task.

DISCUSSION OF RESULTS

Initially, a plot was drawn to present the high and low temperature data on a graph of velocity versus powder weight (Figure 9). A curve fit was accomplished on the data points with a linear model. This provided a compelling case for temperature dependence.

Next, the author was interested in whether taking into account the bullet mass was beneficial even though the testing did not show the bullet mass parameter as being statistically significant. In Figure 10, the data was plotted with the current practice of the abscissa being the load factor, a non-dimensional value defined as "the mass of the powder divided by the mass of the bullet."

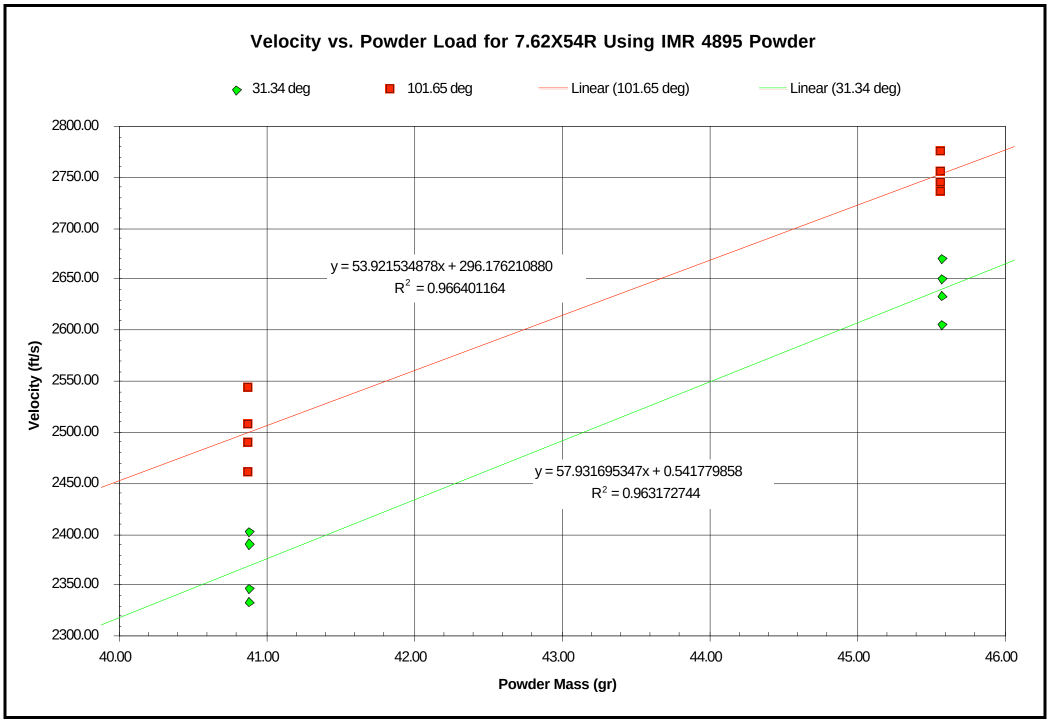

FIGURE 9. Velocity Versus Powder Load.

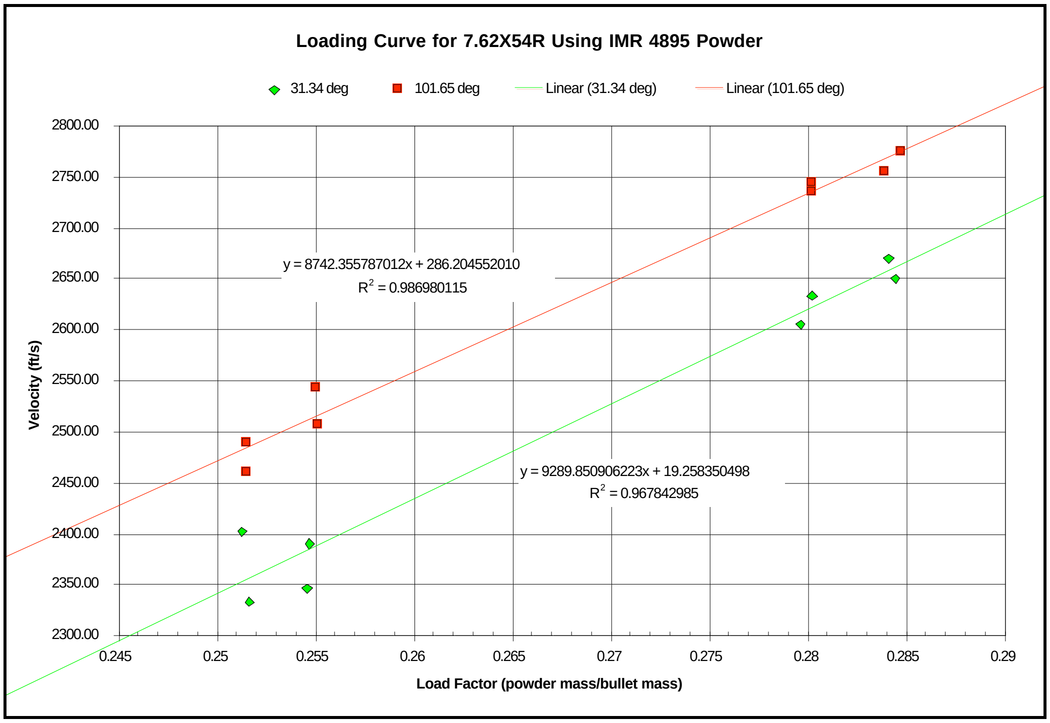

FIGURE 10. Velocity Versus Load Factor.

It is noteworthy that when the data is plotted, taking into account the bullet mass, the R^2 factor is higher (the curve fit is better). R^2 values from the linear models are listed in Table 7.

TABLE 7. Better Correlation of Linear Model with Load Factor.

Abscissa	Powder weight	Load factor
High temperature	0.9664	0.9870
Low temperature	0.9632	0.9678

The linear equations shown in Figure 10 were used as a basis for generating loading curves for any temperature. Standard linear interpolation and extrapolation methods were used on both the slope and y-intercept for generating the multiple curves shown in Figure 11. The hot temperature used in the linear model associated with the equation shown in Figure 10 was the average of the hot temperature data from both the thermocouple in the bore and the thermocouple on the barrel (101.65ºF). The same was done for the cold temperature data (31.34ºF).

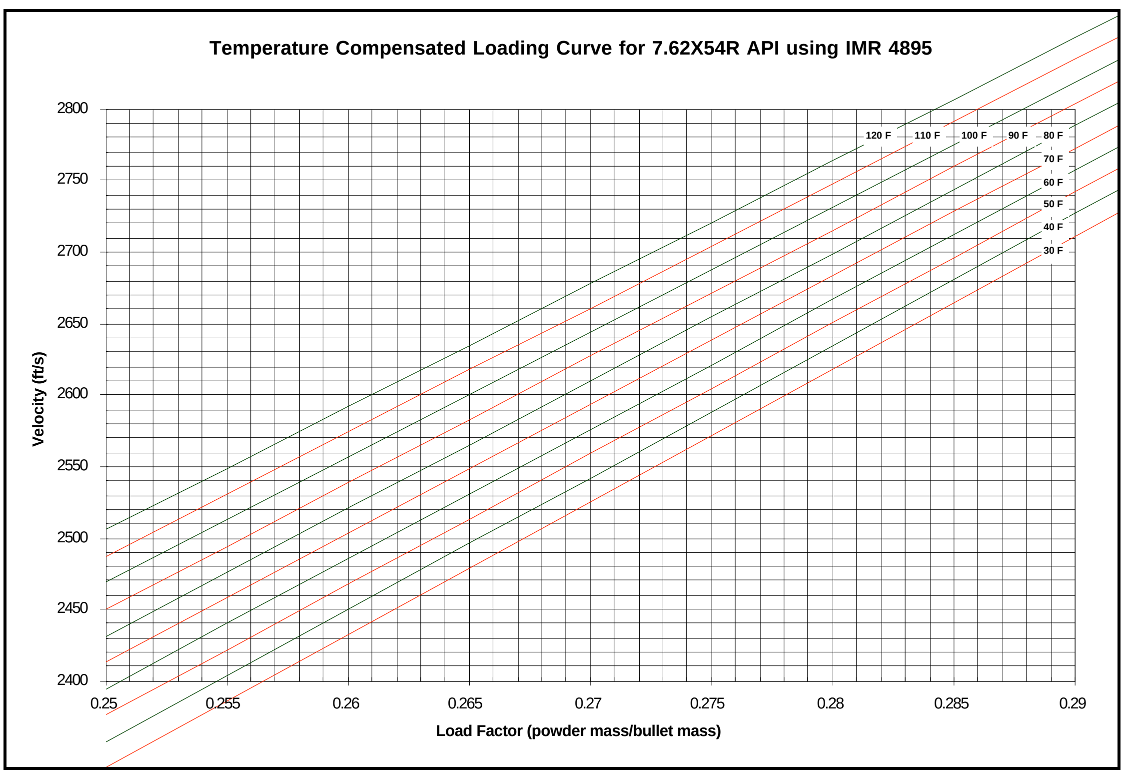

FIGURE 11. Loading Curves Taking Into Consideration Temperature.

A more direct approach to getting the powder load for a given set of test conditions was arrived at by using linear interpolation and solving for the slope and Y-intercept as a function of test temperature. This method was implemented in a Microsoft Excel spreadsheet.

$$\text{Slope} = m = (9534 - 7.787\ T)$$

$$\text{Y-intercept} = b = (3.797\ T - 99.75)$$

Plugging these expressions into the standard equation for a line

$$y = m\ x + b$$

where

y = Velocity

x = Load Factor

and solving for load factor given a desired velocity results in the following expression:

$$\text{Load Factor} = [V - (3.797\ T - 99.75)]/(9534 - 7.787\ T)$$

where

V = desired test velocity in ft/s

T = the temperature at the time of the test in ^{o}F

Once a load factor is determined, multiply by the bullet mass. The product is the amount of IMR 4895 powder that should be used to load the case. The units used for bullet mass and powder mass should be the same.

CONCLUSIONS

The two-level factorial design of experiments approach was used to successfully meet the objectives of this study. Results showed that the powder amount and temperature were the only statistically significant parameters.

Further statistical analysis, using the curve fitting approach, revealed that bullet mass was also an important variable and should be taken into consideration.

Loading curves were generated, taking into account all of the statistically significant variables (i.e., temperature, bullet mass, and powder amount).

The knowledge gained from this study will provide WSL firing officers with the ability to shoot the 7.62 x 54R with accuracy in velocity and repeatability from shot-to-shot.

RECOMMENDATION

The author recommends a practical application of this knowledge as follows.

1. Keep the breach and barrel and bullet at the same temperature.
    a. Shade the Mann gun barrel and breach from direct sunlight.
    b. The ammo should also be in an ammo can in the shade.
2. Use a thermocouple in the chamber of the gun to get the temperature reading.
3. Calculate the amount of powder for the desired velocity and load the round immediately before the test.

Based on the knowledge gained in this study, firing officers who conduct similar tests requiring tight control of velocity can generate temperature compensated loading curves more efficiently, using fewer shots. This effort required 20 rounds shot for statistical requirements. Other caliber efforts could be accomplished in as few as 8 shots.

ADDENDUM

Table 8 presents the analysis of 33 shots, which made use of the temperature compensated loading curve.

The requirement again was for 2,600 ft/s, ±50 ft/s. The data outcome, as can be seen from the table, is 2,598.4 ft/s, ±36.0 ft/s. Out of these 33 shots, **none** were outside of the acceptable range.

Figure 12 shows a histogram of these 33 test velocities.

TABLE 8. Statistical Analysis of Velocities Using Temperature Compensated Loading Curves.

Type	Value
Mean	2598.379364
Standard Error	3.28571488
Median	2600.305522
Mode	N/A
Standard Deviation	18.87499499
Sample Variance	356.2654358
Kurtosis	-1.01715336
Skewness	0.07295208
Range	67.84959127
Minimum	2566.494876
Maximum	2634.344467
Sum	85746.519
Count	33

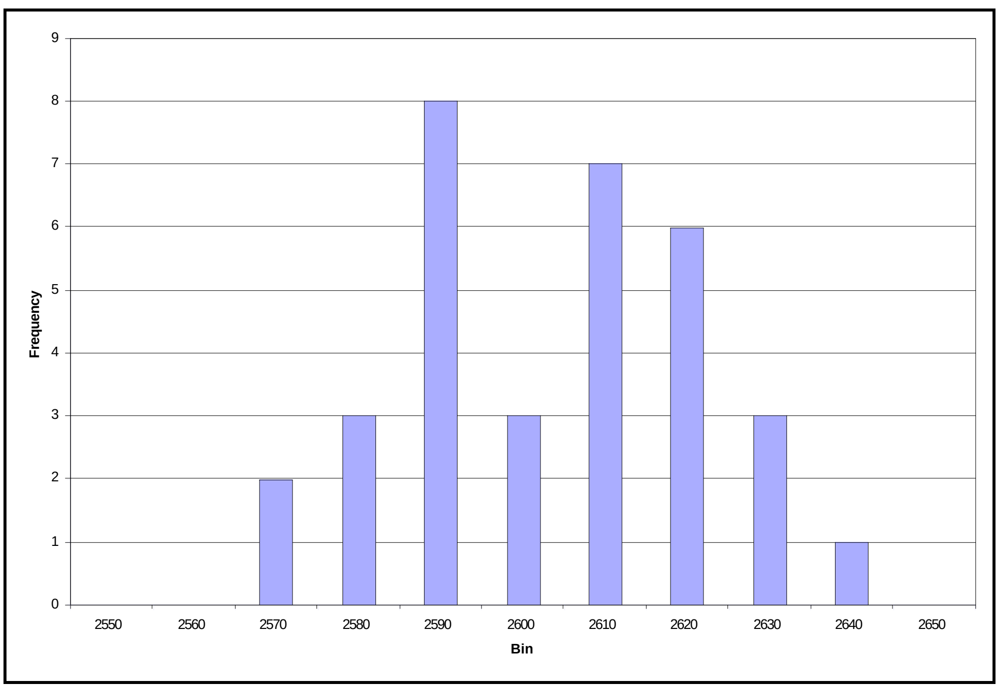

FIGURE 12. Histogram of 33 Test Velocities Measured After This Effort.

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1. John Lawson and John Erjavec. *Basic Experimental Strategies and Data Analysis for Industrial and Quality Improvement Studies*, self-published.

2. Reloaders. http://www.reloadersnest.com (accessed 6 August 2009).

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Appendix

TEST PLAN

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26 January 2009

Test Plan

for

7.62 X 54R Velocity Characterization

J. Hardy Tyson	J. Hardy Tyson	Date 01-26-09
Dave Calvert	David Calvert	Date 01/26/2009
Joe Manchor	Joseph A. Manchor	Date 01/26/2009
Greg Benadom	Greg Benadom	Date 1/27/2009
Jay Kovar	[illegible]	Date 1/27/09

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Introduction/Objective

We continue to have limited success in satisfying our customer requirements for holding impact velocity to +/- 50 feet per second. This test plan is being written to define a test approach that will enable us to identify important variables in controlling velocity and enable us to characterize how to achieve a required velocity with more confidence for our customer.

Approach

The approach to be taken will make use of basic experimental strategies and data analysis using design of experiments methodology enabling us to determine primary variables needing control more easily and with fewer tests than the traditional approach of varying only one variable at a time.

Test Design/Procedures

The method to be used in this testing is known as the two-level factorial design. A two-level factorial design has only two levels of each variable being studied and all possible combinations of the two levels for each of the variables are run as tests. It is postulated that all variables effecting bullet velocity are listed below:

1. Bullet Mass
2. Powder Amount
3. Case Volume
4. Temperature
5. Primer Condition
6. Condition of Barrel (clean / dirty)
7. Compression of Powder

Bullet Mass – bullet mass has manufacturing variability which isn't great (from a sample of 80 bullets; max=163.30 gr, min=158.02 gr) but which might have an effect. For this test we will select high masses that are close together and low masses that are close together for the two levels to be tested.

Powder Amount – this is the typical parameter that is controlled for determining velocity for the hobby handloader and commercial production of cartridges. We will select two different powder loads for this test.

Case Volume – case volume is determined by a number of things. The ones that come to mind are the physical dimensions of the interior of the case during manufacturing; a parameter we do not have control of and which is hard to measure. And case volume is also affected by the depth of the seating of the bullet. A bullet press will be used and the seat height will be controlled consistently.

Temperature – this is not ambient temperature though ambient temperature has an effect. This variable which we will control is more accurately described as soak temperature – powder, case, barrel temperature at equilibrium. The burning of smokeless gunpowder is a chemical process. Chemical processes are affected by temperature the higher the temperature the faster the reaction.

Primer Condition – primers are used to ignite the gunpowder but add a significant amount of energy to the combustion process involved in firing a bullet. It has been noted infrequently that primers are faulty and don't ignite the gunpowder (misfires). Subsequent inspection of these primers have revealed that there is corrosion present in the bottom of the case where the primer flash hole is located. The exact corrosion products and source have not been investigated but this happens. For the cases used in this effort they will be inspected for corrosion prior to use. If corrosion is noted they will not be used.

Condition of Barrel – the amount of control over this parameter is questionable. Certainly the barrel could be cleaned prior to each shot. However the opinions about the effect this has is up for debate. Some precision shooters clean their barrels after every shot. Others, notably competitive target shooters, always shoot a first shot not for the record because it is always a "flier" (not consistent impact point for the same sight picture as subsequent shots). The two states used for this testing will be either cleaned before the shot or not. How many shots have been fired without cleaning will be assumed to not be important to the variable.

Compression of Powder – If the volume of the powder being used is large enough to fill up most of the case, when the bullet is seated it will compress the powder. This will cause the cylindrical grains of powder to fracture, changing the burn rate of the powder. This could cause erratic velocity results. There is a good possibility that this has caused some of the problems seen. It is recommended that for this testing IMR 4895 powder be used because the volume is less than the IMR 4350 which has been used to date.

From this set of variables it is being claimed that the Independent Variables (ones that can be controlled) are:

1. Bullet Mass, (m)
2. Powder amount, (q)
3. Temperature, (T)
4. Condition of Barrel (clean / dirty), (c)

The Dependant Variable in this series of tests is:

1. Velocity, (V)

The Lurking Variables (ones we have no control over) are at a minimum:

1. Case Volume
2. Primer Condition
3. Compression of Powder
4. Unknown

Given the above stated variables the two level factorial design test approach is delineated in Table 1 below.

Table 1 Two Level Factorial Test Design with 2^4 Variables

Run	Bullet Mass	Powder	Temperature	Barrel clean/dirty
1	-	-	-	-
2	+	-	-	-
3	-	+	-	-
4	+	+	-	-
5	-	-	+	-
6	+	-	+	-
7	-	+	+	-
8	+	+	+	-
9	-	-	-	+
10	+	-	-	+
11	-	+	-	+
12	+	+	-	+
13	-	-	+	+
14	+	-	+	+
15	-	+	+	+
16	+	+	+	+

Where the "+" sign is defined as the high option of the variable and "-" is the low option of the variable defined for each variable in Table 2.

Table 2 Low and High Options for the Test Variables

Condition	+	-
Bullet Mass (m)	>162.452 gr	<160.603 gr
Powder amount (q)	45.57 gr	40.88 gr
Temperature (T)	100° F (Anti-freeze pipe wrap stabilized)	32° F ("Cold ambient")
Condition of Barrel (c)	Clean immediately before shot	Un-cleaned Barrel

The mass of 100 bullets was taken and an average and standard deviation were calculated. The bullet mass variable + will use bullets that are at least 1.35 standard deviations heavier than the average (the heaviest bullet will not be used) and the – will use bullets that are at least 1.35 standard deviations lighter than the average (the lightest two bullets will not be used).

The powder amount was determined from a loading curve generated from data downloaded from the web (www.reloadersnest.com). The bullet mass from the data collected was165 gr and that was used to calculate a velocity which would give 2500 fps for the "-" condition and 2700 fps for the "+" condition.

Table 1 is a systematic list of the tests called the standard order or Yates order. This order is convenient for listing experimental results or analyzing them but, the experiments should not be run in this order, since the risk of bias intentional or otherwise would be very great. The tests will be run in random order as listed in Table 3.

Table 3 Random Order of Tests to be Run

Test	Run	Bullet #	Bullet Mass (m)	Powder (q)	Temperature (T)	Barrel (c)
1	16	95	162.64 gr	45.57 gr	100° F	Clean
2	7	53	160.06 gr	45.57 gr	100° F	-
3	11	67	160.22 gr	45.57 gr	32° F	Clean
4	6	31	162.54 gr	40.88 gr	100° F	-
5	10	64	162.48 gr	40.88 gr	32° F	Clean
6	13	98	160.24 gr	40.88 gr	100° F	Clean
7	1	33	160.54 gr	40.88 gr	32° F	
8	4	23	162.64 gr	45.57 gr	32° F	-
9	9	54	160.60 gr	40.88 gr	32° F	Clean
10	14	90	162.58 gr	40.88 gr	100° F	Clean
11	8	49	162.64 gr	45.57 gr	100° F	-
12	2	18	162.72 gr	40.88 gr	32° F	-
13	12	71	162.98 gr	45.57 gr	32° F	Clean
14	5	52	160.34 gr	40.88 gr	100° F	-
15	3	44	160.42 gr	45.57 gr	32° F	-
16	15	100	160.54 gr	45.57 gr	100° F	Clean

Center Points – are included in this test because 1) they provide an estimate of error against which effects can be measured and 2) they provide a test on the model. Center points allow us to check for curvature by seeing if there is a big difference between the center point average and the average of the factorial points. 3) they also allow for a test of repeatability. Table 4 is a list of center point tests.

Table 4 Conditions for Center Point Tests

Center Point Run	Bullet #	Bullet Mass (m)	Powder (q)	Temperature (T)	Barrel (c)
1	7	161.54 gr	43.23 gr	ambient	Clean
2	63	161.54 gr	43.23 gr	ambient	Clean
3	73	161.52 gr	43.23 gr	ambient	Clean
4	80	161.54 gr	43.23 gr	ambient	Clean

Variable "barrel" is a discrete variable and has no center point therefore center point testing will be performed with a clean barrel.

Data Requirements

Each of the parameters (bullet mass, powder amount, temperature and barrel cleanness) needs to be controlled. Most of the support equipment is available to control these parameters. The bullet masses were selected from a group of 100 pulled and measured bullets. The powder amount was determined from a loading curve generated from data downloaded from the web (www.reloadersnest.com). The temperature will be controlled and measured via thermocouple on the barrel breach. High temperature will be controlled using electric pipe wrap used to keep pipes from freezing. Low temperature will be controlled by using ice in an ice chest and blowing a fan across the ice onto the barrel breach. Standard barrel cleaning material is available. Velocity will be measured using the new fracturing graphite barrel muzzle velocity measuring device and break paper.

Analysis of Data

In order to determine which independent variables and interactions have a statistically significant effect on the dependant variable a numerical analysis is necessary. Table 5 is a computation table for systematically calculating if the independent variables effects and interactions are statistically significant. The statistical significants will be determined by calculating the signal-to-noise ratio for each of the variables and interactions and comparing these values to the standard "Student's t-statistic." We will assume a 95% confidence level with n-1 degrees of freedom = 15, which gives a t-statistic of 2.131. Any and all of the signal-to-noise ratios (t_E) greater than 2.131 are statistically significant. The independent variables which turn out to be significant will be taken into consideration when down loading rounds for a desired velocity.

The Equation for predicting outcome for a 2^4 factorial design is:

$$
\begin{aligned}
V = {} & b_0 \\
& +b_1m+b_2q+b_3T+b_4c \\
& +b_{12}mq+b_{13}mT+b_{14}mc+b_{23}qT+b_{24}qc+b_{34}Tc \\
& +b_{123}mqT+b_{124}mqc+b_{134}mTc+b_{234}qTc \\
& +b_{1234}mqTc
\end{aligned}
$$

Where:
The "b" values are constants
m = Mass of bullet
q = amount of powder
T = the temperature
c = cleanness of barrel

The variables and interactions that turn out not to be significant will be dropped from the preceding equation.

Additional focused testing might be necessary to refine the above constants in generating a loading curve incorporating all the significant variables.

Table 5 Worksheet for Calculation of Effects and Interactions.

Run	Mean	Bullet Mass	Powder	Temperature	Barrel	Bullet Mass:Powder	Bullet Mass:Temp	Bullet Mass:Barrel	Powder:Temperature	Powder:Barrel	Temperature:Barrel	Bullet Mass:Powder:Temp.	Bullet Mass:Powder:Barrel	Bullet Mass:Temp:Barrel	Powder:Temp:Barrel	Bullet Mass:Powder:Temp:Barrel	Velocity
1	+	-	-	-	-	+	+	+	+	+	+	-	-	-	-	+	
2	+	+	-	-	-	-	-	-	+	+	+	+	+	+	-	-	
3	+	-	+	-	-	-	+	+	-	-	+	+	+	-	+	-	
4	+	+	+	-	-	+	-	-	-	-	+	-	-	+	+	+	
5	+	-	-	+	-	+	-	+	-	+	-	+	-	+	+	-	
6	+	+	-	+	-	-	+	-	-	+	-	-	+	-	+	+	
7	+	-	+	+	-	-	-	+	+	-	-	-	+	+	-	+	
8	+	+	+	+	-	+	+	-	+	-	-	+	-	-	-	-	
9	+	-	-	-	+	+	+	-	+	-	-	-	+	+	+	-	
10	+	+	-	-	+	-	-	+	+	-	-	+	-	-	+	+	
11	+	-	+	-	+	-	+	-	-	+	-	+	-	+	-	+	
12	+	+	+	-	+	+	-	+	-	+	-	-	+	-	-	-	
13	+	-	-	+	+	+	-	-	-	-	+	+	+	-	-	+	
14	+	+	-	+	+	-	+	+	-	-	+	-	-	+	-	-	
15	+	-	+	+	+	-	-	-	+	+	+	-	-	-	+	-	
16	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
Σ(+)																	
Σ(-)																	
Σ(+) + Σ(-)																	
Σ(+) - Σ(-)																	
Effects																	
t_E																	

The sign in the shaded boxes is a result of the product of the signs in the corresponding columns.

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