What is the best

Load Development Approach?

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Overview

Many load development procedures are focused on using the minimum number of shots to arrive at a combination of bullet, propellant weight, and overall cartridge length that shoots the smallest groups possible for a particular firearm. This is a laudable goal as it saves time and money, and there are a few approaches out there that get the job done. The standard “ladder test” approach and the “Satterlee” approach will be examined, and some of the pitfalls of the various approaches are identified. To quote Carl Sagan: “Extraordinary claims must be backed with extraordinary proof.” As of the current day, the extraordinary proof that abbreviated load development actually works has yet to be presented.

Background

Many shooters perform load development with a charge increment (e.g. “ladder” test) and look for statistically insignificant velocity “nodes” (e.g. plateaus) without shooting bullets at paper. Based on these results, a series of 3 shot groups is then fired, using the Extreme Spread target measurement metric while varying cartridge overall length to select cartridge length exhibiting minimum group size. A much more reliable and statistically defensible method is presented using a sizeable sample of muzzle velocity and targeting data provided by a well-known ammunition manufacturing company for the 6.5mm Creedmoor cartridge.

Procedure

Bullet Selection

The shooter should select a bullet for their cartridge and application based on expected target (paper or hunting) and maximum target engagement range. Then consult the bullet manufacturer’s loading manual for recommended powders, selecting the propellant based on the procedure detailed below.

Powder Research & Selection

Upon selecting the projectile for your application, consult the most current reloading manual for suggested propellants for your bullet/cartridge combination. Then, do a little math on the propellants recommended to select the propellant with the lowest muzzle velocity change between maximum and minimum powder loads for the given difference in charge weights. Table 1 shows the powders and charge weights for a 6.5mm Creedmoor cartridge with bullet weights between 140g and 143grains. The right-hand side of Table 1 shows the muzzle velocity sensitivity of each recommended powder in the second to last column, with the H4350 highlighted as having the lowest muzzle velocity sensitivity for a 1 grain change in charge weight.

Propellant Designation	Min Charge, Grains	Min Charge MV, FPS	Max Charge, Grains	Max Charge MV, FPS	Propellant Geometry	Max-Min MV Sens., FPS/grain	Max Charge Efficiency, FPS/grain
Norma 203-B	32.5	2400	37.3	2650	Tubular	52.1	71.0
Varget	32.7	2400	36.4	2600	Tubular	54.1	71.4
Alliant RL-15	33.5	2400	37.9	2650	Tubular	56.8	69.9
BIG GAME	35.1	2400	41.4	2750	Tubular	55.6	66.4
Alliant RL-17	35.3	2400	41.3	2750	Tubular	58.3	66.6
Norma URP	35.3	2400	41.4	2750	Tubular	57.4	66.4
Hybrid 100V	35.6	2400	41.3	2750	Ball	61.4	66.6
WIN 760	35.9	2400	41.3	2700	Ball	55.6	65.4
IMR 4350	36.1	2400	42.0	2750	Tubular	59.3	65.5
H 4350	35.6	2400	41.5	2700	Tubular	50.8	65.1
IMR 4451	36.6	2400	41.3	2650	Tubular	53.2	64.2
Superformance	38.2	2400	44.7	2800	Ball	61.5	62.6

Table 1: 140g-143g Loads for 6.5mm Creedmoor; Hornady 10th Edition

By selecting the powder with the lowest muzzle velocity/charge weight sensitivity, the shooter is assured of minimum muzzle velocity changes for the small, and sometimes uncontrollable, changes in loaded charge weight within the error of measurement of the reloaders scales. The powder with minimum muzzle velocity sensitivity to charge weight changes will likely change depending on the primer being used, so the reloader is advised to perform a ladder test of their own to ensure the slope of change in muzzle velocity with change in charge weight closely matches (<10% difference) the published slope. Offsets to the published velocity vs charge weight slope can be caused by changes in barrel dimensions, case volume, primer output, bullet dimensions or weight, etc. and should be expected. If the published Muzzle Velocity / Charge Weight slope does not closely match the published slope, the reloader is advised to approach maximum loads with caution.

Charge Ladder Test

Reloaders typically conduct a “ladder test” when working up a new load for a particular rifle with the goal of discovering the optimum charge weight for the bullet/cartridge combination that provides the smallest group. Many reloaders skip the paper target altogether, and instead focus only on recording the muzzle velocity of each bullet in the shot string, looking for ”plateaus” or “flat spots” in the Muzzle Velocity / Charge Weight performance; so-called “velocity nodes”. Figure 1 shows the first 5 results of a charge ladder test conducted on a 6.5mm Creedmoor cartridge firing a 140g bullet with copper alloy jacket and lead core using various charge weights of H4350 propellant.

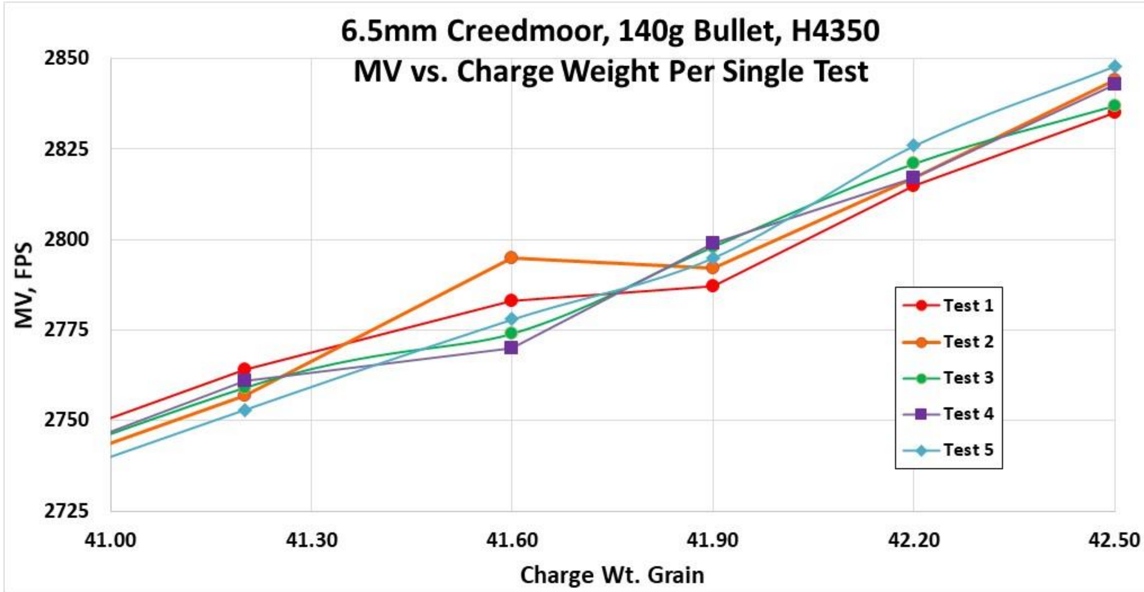

Figure 1: MV vs Charge Weight for 6.5mm Creedmoor w/ 140g Bullets and H4350 Powder, First 5 Ladder Tests

Some reloaders might think that based on the "flat spot" of the second test, a charge of 41.7 grains or 41.8 grains of H4350 should be loaded, but as will be shown, that would be the wrong charge to achieve smallest groups, and that a charge weight of 41.9 grains should be avoided. As will be shown, the 5 shot muzzle velocity sample is much too small to provide a representative performance of the repeatability of the 41.9g charge weight.

So, what's wrong with looking for "flat spots" in the Muzzle Velocity / Charge Weight performance? Isn't it a good idea to look for places in the muzzle velocity / charge weight behavior where the muzzle velocity is least sensitive to changes in charge weight? Well, nothing, except for the fact that there are significant shot-to-shot changes in bullet engraving pressure that are beyond the ability of the reloader to control, that can easily swing peak chamber pressure by 1000 PSI and the muzzle velocity plus or minus 3-4 FPS or more. The data shown in Figure 2 was gathered in 2003 and presented in 2004 at National Defense Industrial Association Small Arms Conference in Las Vegas, NV. (see: https://ndia.dtic.mil/2004/2004arms.html).

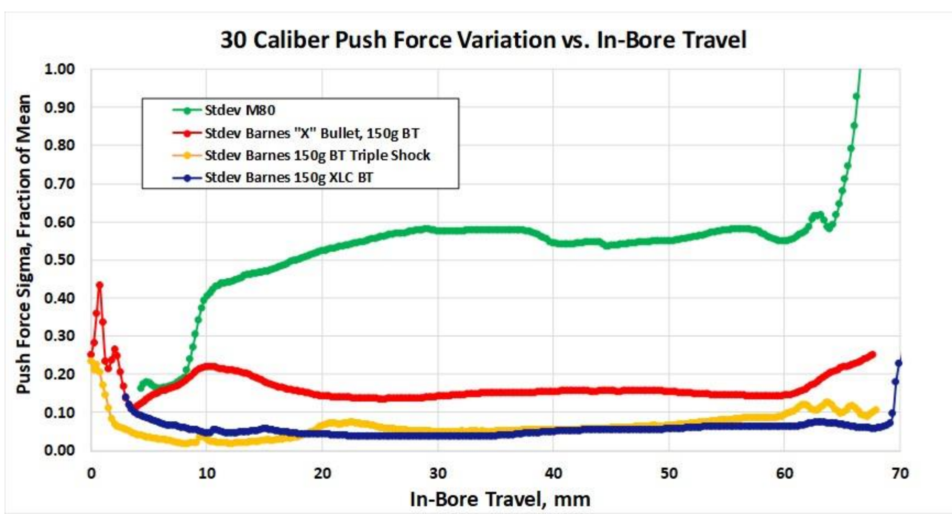

Figure 2: Measured 7.62mm Engraving Force Variability

The shot-to-shot variability in bullet engraving pressure and the effect this has on resulting muzzle velocity makes choosing a charge weight based on a single shot at one charge weight a statistically risky proposition.

Analysis of **all** the shots (>200) fired in 6.5mm Creedmoor cartridge testing show considerable muzzle velocity variation and "velocity nodes" can be obtained at almost any charge weight by selecting the desired muzzle velocity at the charge weight of interest. Figure 3 shows the muzzle velocities for the whole data set obtained at each charge weight, connected with lines linking them by firing sequence (e.g. first shot at 41.2g is connected to the first shot at 41.6g, then to the first shot at 41.9g, etc.). Where a "velocity node" is found depends on which shot sequence is chosen, **and nothing more**.

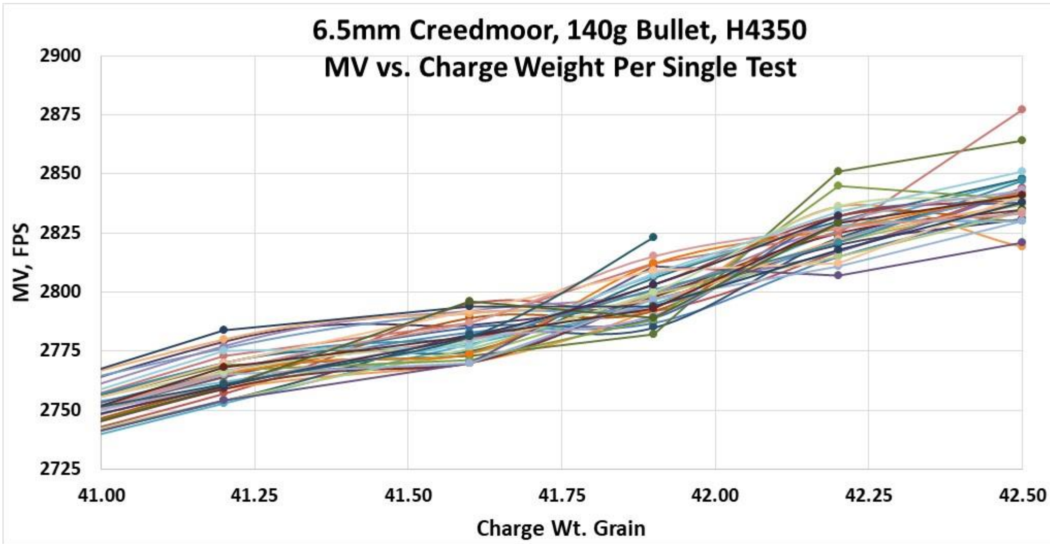

Figure 3: Muzzle Velocity vs. Charge Weight for 6.5mm CM Cartridge

A summary of the whole data set of 6.5mm Creedmoor muzzle velocity data shown in Figure 3 is listed in Table 2.

The number of shots per charge weight is greater than 32, so the average muzzle velocity is well known, as is the shot-to-shot variation (standard deviation, or sigma) of this primer/propellant/projectile combination. It is interesting to note that with the large number of shots fired per charge weight, the true muzzle velocity at each charge weight is known at 95% confidence level to within an error of less than 4.0 FPS (2x the values in the Std. Error of Mean column).

Charge Wt., Grains	Mean MV, FPS	MV Sigma, FPS	Std. Error of mean, FPS	n=
40.0	2683.7	11.2	1.90	35
41.2	2765.4	7.9	1.33	35
41.6	2781.1	8.0	1.35	35
41.9	2798.8	9.3	1.57	35
42.2	2825.7	9.2	1.59	34
42.5	2839.7	11.0	1.94	32

Table 2: 6.5mm Creedmoor Muzzle Velocity Mean & Standard Deviation Summary

Examining all the muzzle velocity data, if the intent is to develop a load for long-range shooting, the 41.2 grain and 41.6 grain charges are expected to be best due to their low muzzle velocity standard deviations. The next question is: “Does either of these charge weights **ALSO** deliver smallest group size?”

Data Collection & Analysis of Group Size

Once targets have been fired, the next task is analysis of the group size. The “OnTarget Target Data System” provides a simple and easy way to collect impact point data on each shot in each COAL group. The “OnTarget” Target Data System makes collection and analysis of targeting data quick, accurate and simple.

Figure 4 shows the OnTarget Target Data System in use for a 17 caliber rifle target.

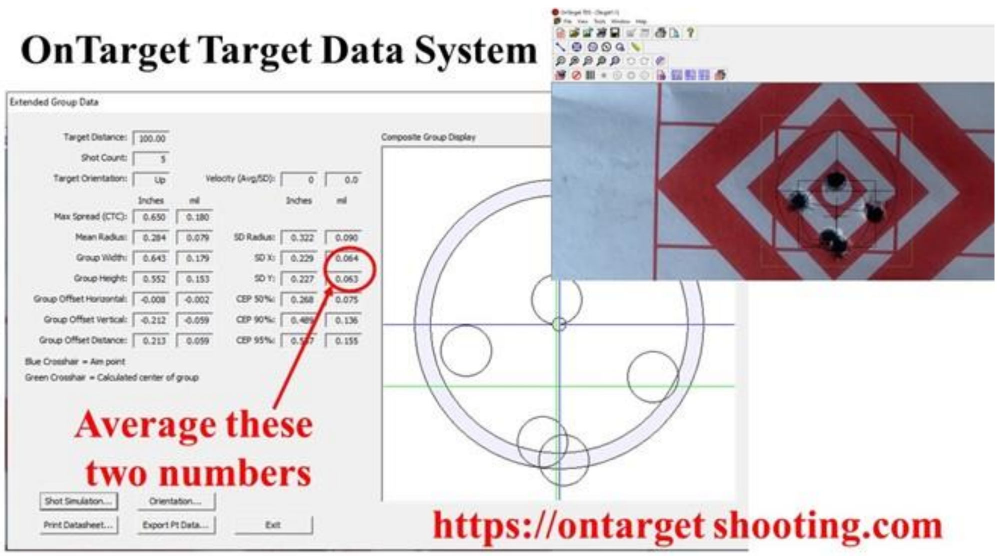

Figure 4: **OnTarget Software Target Data Analysis**

Examining the targeting data provided, using the typical 3 shot extreme spread targeting metric for the first 5 groups at each charge weight ladder test results in the data shown in Figure 5. Here, if the extreme spread of 3 shot groups, or even the average extreme spread of the first 5 three shot groups were only considered, a charge weight of 42.1-42.3 grains might look like the best option.

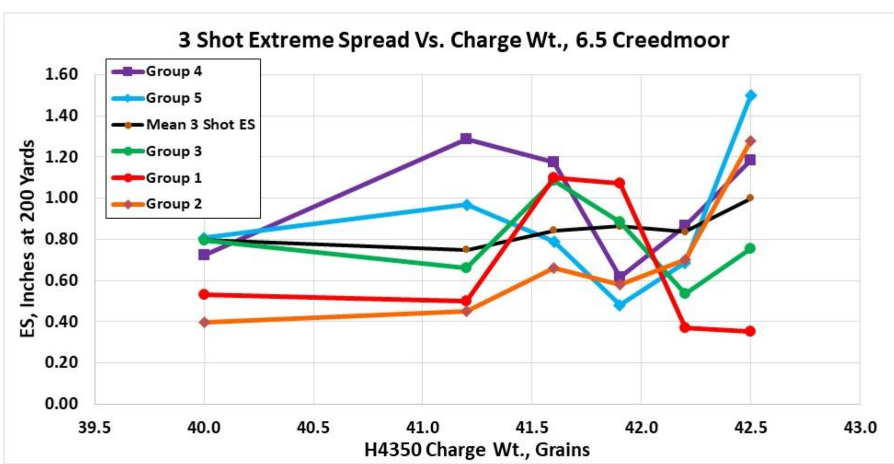

Figure 5: 6.5mm Creedmoor; 3 Shot Extreme Spread at 200 Yards, First 5 Groups

However, when examining **all** the targeting data provided using the Extreme Spread dispersion performance metric for 3 shot groups, no particularly clear trend emerges, as shown in Figure 6. For purposes of comparison, a plot of the average of horizontal and vertical standard deviation using 5 shots is plotted in red, while the group size variability for 5 shot H&V standard deviation is plotted in light green.

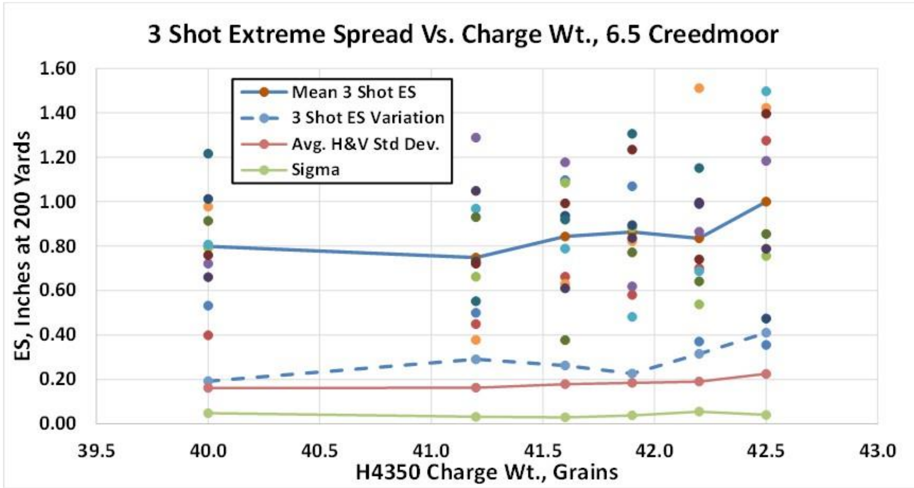

Figure 6: 140g Group Size versus Charge Weight

In Figure 6, there is clearly a very large amount of scatter in the group size performance at each charge weight when using the Extreme Spread dispersion metric for 3 shot groups. Trying to pick a charge weight yielding lowest group size using the data contained in Figure 6 would prove nearly impossible.

Figure 7 shows why this is so difficult. In the upper left-hand corner is circled the **AVERAGE** dispersion variation for 3 shot groups using the extreme spread targeting metric as a fraction of the true dispersion; nearly 60%. In contrast, the same data (holes in paper) using an average of the horizontal and vertical standard deviations for 5 shot shows a variability of about 25% of the true dispersion. Thus, by changing the evaluation metric from “Extreme Spread” to the “average of horizontal and vertical Standard Deviation”, and increasing the number of shots from 3 to 5, the uncertainty in group size performance can be cut by more than 60%.

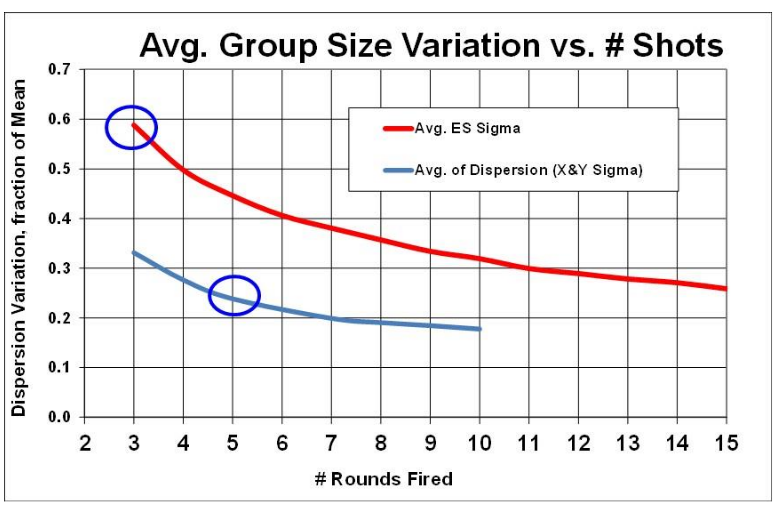

Figure 7: Group Size Variation for 3 & 5 shots using Extreme Spread & Avg of H&V Sigma

Once the bullet impact points have been acquired and the data collected into five shot groups, the "OnTarget Software" will calculate the standard deviations of the impact points in the horizontal and vertical axes. The average of these two values should be used to make comparisons among different loads. The reason for using the average of the horizontal and vertical standard deviations is shown in Figure 8. Moving from right to left on Figure 8, comparing among several methods to assess the true dispersion (group size) as the group becomes increasingly asymmetric, averaging (the blue line) the horizontal and vertical standard deviations most closely follows the "True CEP" (Circular Error Probable, true dispersion) of the methods examined.

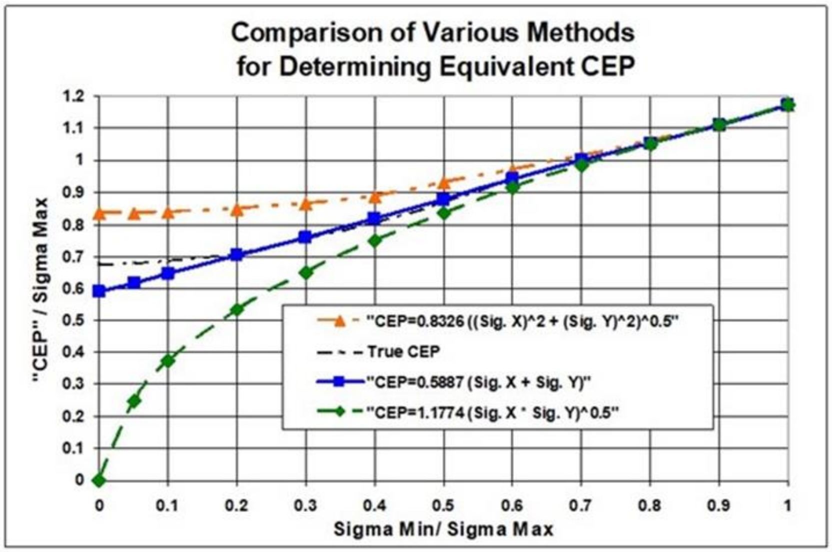

Figure 8: Comparison Methods for Skewed Fall of Shot Distributions

Using the average of the horizontal and vertical distributions for several fired groups, the dispersion performance among the groups can be compared at a desired level of statistical significance using the "Student's T Test ".

Equation 1 shows the "Student's T Test equation.

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

Equation 1: The Student's T Test

Where:

$\bar{X}_1$= Sample Mean, Population 1
$\bar{X}_2$= Sample Mean, Population 2
s_1^2= Standard Deviation Squared, Population1
s_2^2= Standard Deviation Squared, Population 2
n_1 = Number of Samples, Population 1
n_2 = Number of Samples, Population 2

A calculation for each pair of tests can then be made, and the result of each pair of group size data can be compared to the "T-Critical" value shown in Table 3, selecting the $T_{critical}$ value that corresponds with the confidence level of interest.

	Confidence Level			
DOF	90.0	95.0	97.5	99.0
1	3.078	6.314	12.706	31.821
2	1.866	2.920	4.403	6.965
3	1.638	2.353	3.182	4.541
4	1.533	2.132	2.776	3.747
5	1.476	2.015	2.571	3.365
6	1.440	1.943	2.447	3.143
7	1.415	1.895	2.365	2.998
8	1.397	1.860	2.306	2.896
9	1.383	1.833	2.262	2.821
10	1.372	1.812	2.228	2.764
11	1.363	1.796	2.201	2.718
12	1.356	1.782	2.179	2.681
13	1.350	1.771	2.160	2.650
14	1.345	1.761	2.145	2.624
15	1.341	1.753	2.131	2.602
16	1.337	1.746	2.120	2.583
17	1.333	1.740	2.110	2.567
18	1.330	1.734	2.101	2.552
19	1.328	1.729	2.093	2.539
20	1.325	1.725	2.086	2.528
21	1.323	1.721	2.080	2.518
22	1.321	1.717	2.074	2.508
23	1.319	1.714	2.069	2.500
24	1.318	1.711	2.064	2.492
25	1.316	1.708	2.060	2.485
26	1.315	1.706	2.056	2.479
27	1.314	1.703	2.052	2.473
28	1.313	1.701	2.048	2.467
29	1.311	1.699	2.045	2.462
30	1.282	1.645	1.960	2.326

Table 3: List of T Critical Values vs. Degrees of Freedom & Confidence Level

For purposes of this article, the group sizes for the data were compared to group sizes fired with the 42.5 grains of H4350. As seen in Table 4, all the charge weights except the 42.2g charges shot smaller groups than the 42.5g baseline. Similar comparisons can be made amongst the other groups.

So, is the dispersion (group size) picture any clearer if the targeting performance criteria is switched to an average of the horizontal and vertical standard deviations and the number of shots per group is increased from 3 to 5? Emphatically, YES! The average of the horizontal and vertical group size standard deviation for 5 shot groups by charge weight is listed in Table 4. By applying the "Student's T Test" shown just prior, it is possible to compare the results in Table 4 relative to one another for a desired confidence level. When comparing two targeting data sets of 7 groups each, the Degrees of Freedom is calculated to be 11.

Charge Wt., Grains	Avg. H&V Std Dev., in.	Group Size Sigma, in.	# of Groups	T Test WRT 42.5g	Different Than 42.5g?
40.0	0.161	0.047	7	2.744	**Yes @ 99% CL**
41.2	0.162	0.031	7	3.294	**Yes @ 99.5% CL**
41.6	0.179	0.029	7	2.463	**Yes @ 97.5% CL**
41.9	0.184	0.038	7	1.966	**Yes @ 95% CL**
42.2	0.190	0.055	7	1.362	**Same**
42.5	0.225	0.040	7	----	**----**

Table 4: 6.5mm Creedmoor Dispersion Data (Avg H&V) for 5 Shot Groups

In Figure 9, the muzzle velocity variability, average dispersion, and dispersion variability are plotted as a function of the charge weight using average of the horizontal and vertical standard deviation group size metric (not the 3 shot extreme spread metric). Notably, the smaller group sizes are strongly correlated with low variation in muzzle velocity with charge weights above 40.5g of H4350. This observation reinforces the theory that consistent in-bore travel times minimize dispersion contributions from barrel pointing variability.

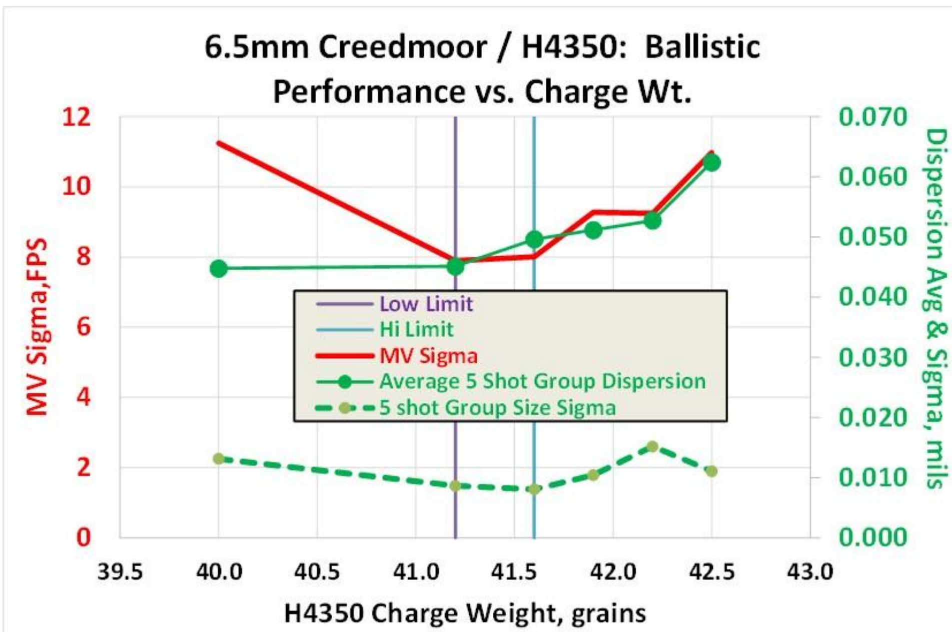

Figure 9: Dispersion Results of 140g 6.5mm Creedmoor

The 15 shot group size for the provided 200+ shot targeting data in rolling 15 shot groups are shown in Figure 10.

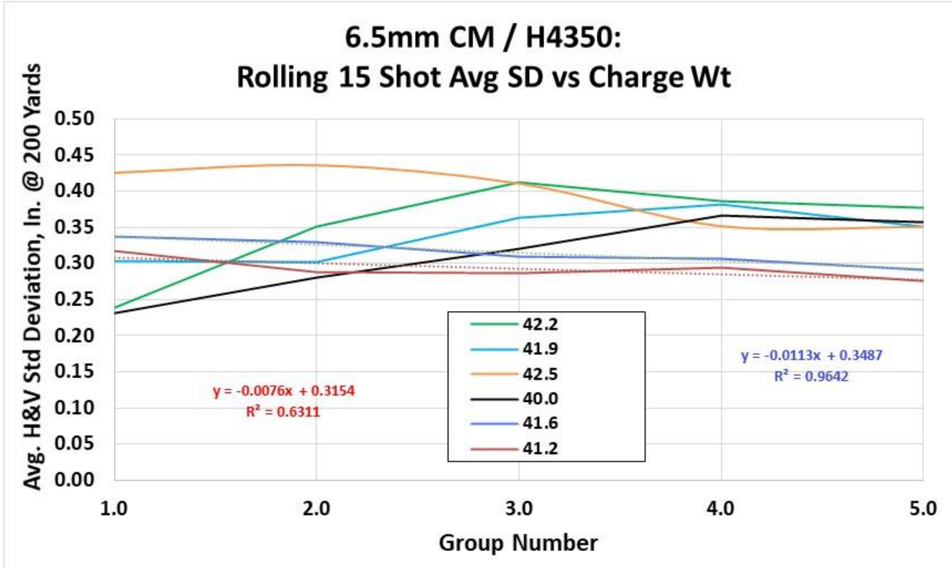

Figure 10: 6.5mm Creedmoor Dispersion; Rolling 15 Shot Groups

Interestingly, the dispersion performance of the 41.2g and 41.6g charge weights are remarkably flat compared to the other charge weights, indicating the desired consistency in dispersion performance.

Summary

Analysis of the muzzle velocity data "strings" and the 3 shot extreme spread shot groups show it would have been unlikely a reloader would have been able to select the correct charge weight to yield smallest group size from either the "Velocity node" or 3 shot extreme spread group size metrics. Shooters and reloaders are looking for "shortcuts" for load development are advised to:

1. Fire all load development shots at paper targets and measure muzzle velocity for each shot.
2. Change their fall of shot target evaluation metric from "3 shot Extreme Spread" to the average of horizontal and vertical standard deviation of fall of shot for a 5 shot group.
3. Use a rolling average of the horizontal and vertical standard deviation for 5 shot groups in 15 shot groups to monitor dispersion performance. If the dispersion of rolling 15 shot groups isn't close to a straight line, you should consider exploring other load options.