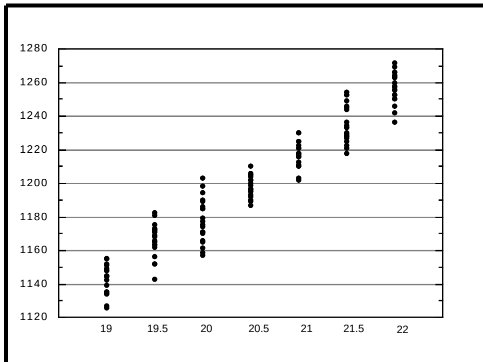
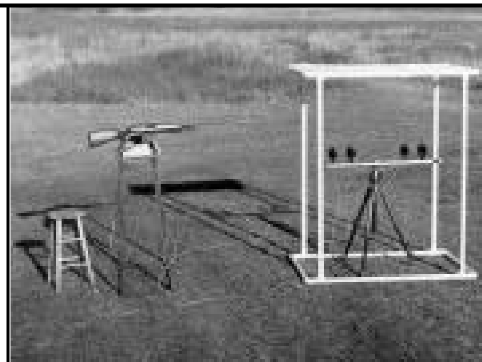
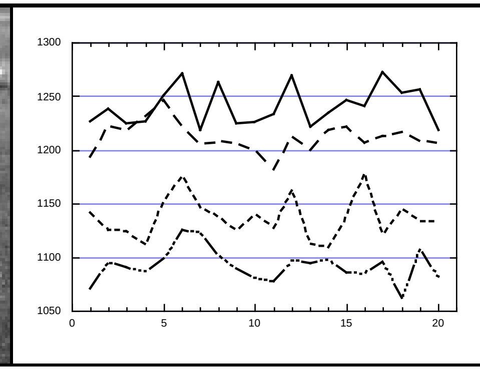
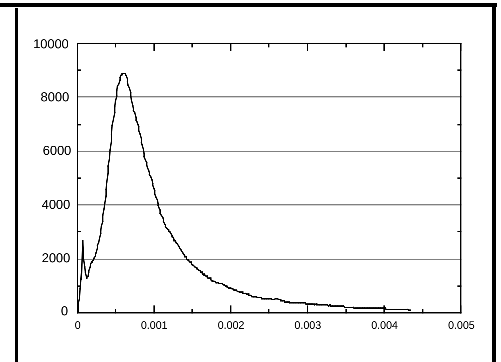
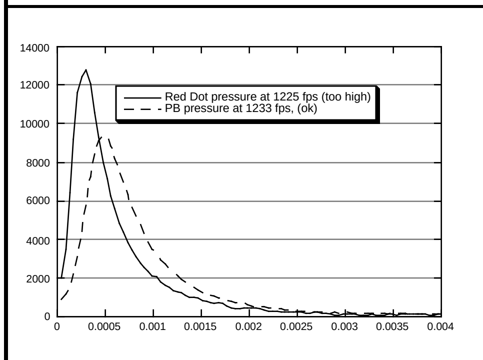










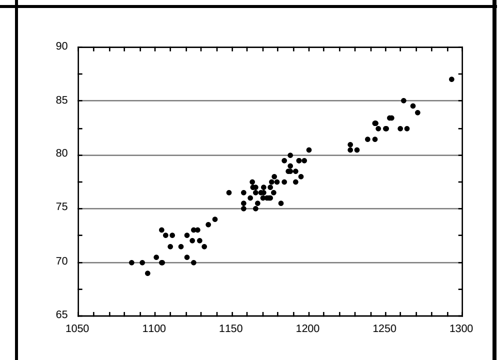
Chronographing Shotguns

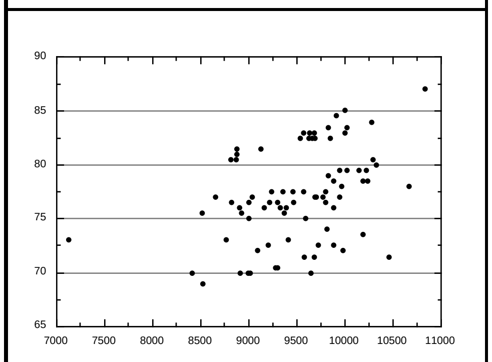
&

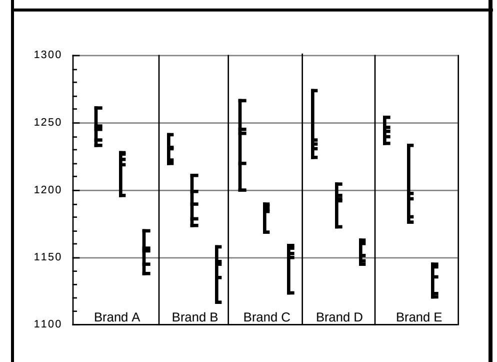
Measuring Their Recoil

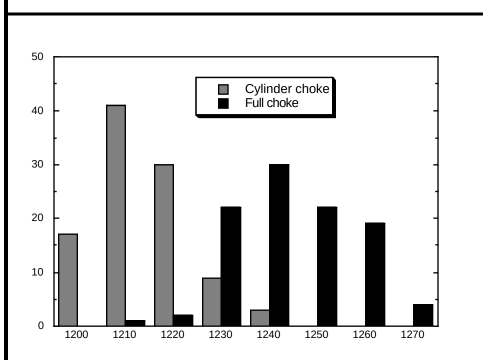
by Neil Winston

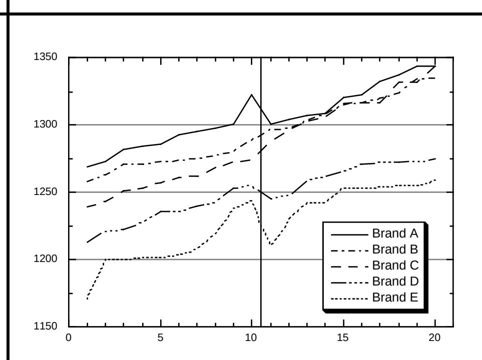
©November 2001

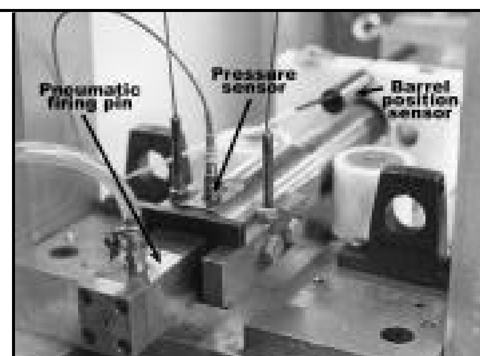


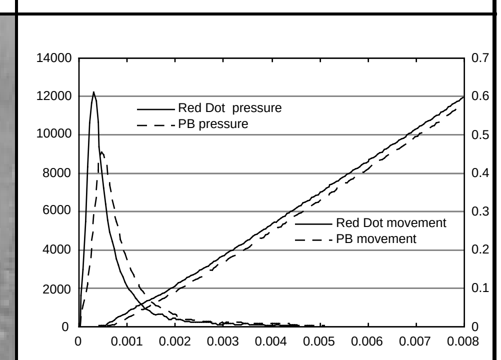












Preface

The ATArule regarding the maximum speed of shells was recently reworded. The previous reference to a “3-dram equivalent loading” has been scrapped in favor of the following explicit standard:

RULE III, I.3. *(A contestant cannot use) 3. Any load with a velocity greater than 1290 fps (feet per second) with maximum shotcharge of 1 1/8 ounces (31.89 grams), or 1325 fps with a maximum shot charge of 1 ounce (28.30 grams), or 1350 fps with a maximum shot charge of 7/8 ounce (24.80 grams), as measured in any individual shot - shell. These velocities are maximum and no individual shotshell shall exceed these limits for the designated shot charge...*

The old rule, based on SAAMI standards, referred to specifications which few understood and no one knew how to find. The effect of this new rule is to set down explicit limits for the speed of shells used in ATA competition, limits against which a suspect shell could be tested. The response to this change has been mixed. Few object to dropping a standard which has been out-of-date for eighty years but many call the above rule unenforceable. Of these, some even favor dropping the speed rule entirely and regulating shells by shot-weight only. In any case, shot velocity is again a popular topic around the clubs.

At the same time shotgun magazines, both print and electronic, have begun to feature articles based on shell speed: What is the effect of changing components? How many times can you reload a casing? How fast does this newest factory offering go?

The problem is that neither at the clubs nor in the magazines is there any serious consideration of the chronography which lies behind the numbers which are quoted, printed, or which appear on the readout of the experimenter’s home chronograph.

SECTION 1

- INTRODUCTION
- CHRONOGRAPH TYPES
- TESTING CHRONOGRAPHS
- INTERPRETING RESULTS

We think of shotshell velocity as a robust statistic, the unvarying product of a set of components which will give similar velocity readings through any properly used chronograph. In truth, velocity is anything but that. It is a deceptive, changeable, and maddening phantom which exists as much in the chronograph as in the shell.

The usual shotgun magazine fare—"the shell clocked a healthy 1211 feet per second over the Oehler Model 34 skyscreens"—is almost useless as a generalization about that type of shell, but I cannot fault our journalists for just giving us the bare numbers and nothing more. If you even scratch the surface of shell chronography, you have to go on and say more than anyone wants to hear. And besides, an interested shooter can buy a chronograph and get real use from it without thinking any further than the numbers which appear on the readout. If he continues to use exactly the same chronograph setup and the same gun and choke, he can test and compare factory loads. If he reloads, he can keep closer tabs on his production than can a reloader who doesn't have a chronograph.

But you can't generalize from the magazine's or the home loader's results to make a direct statement such as "this kind of reload goes 1200 feet per second." The shot velocity reading you get from a chronograph is not merely influenced by, but is *largely determined by*, the particular chronograph setup which is used, and changing anything about the test will change the results. The following report covers the "Dark Side" of chronography, the problems and caveats which don't appear in print. The precision required in the setup, the large and unexplainable influence of seemingly trivial or unmeasurable factors, even the question of what it is a chronograph is measuring—all these have been ignored in the shotgun press and of course never come up at the gun club. For this reason we will spend a long time studying the basics. What are chronographs, how do they work, and what do they measure? What do we mean when we quote the speed of a shotgun shell?

Like patterning, chronographing is a tedious and time-consuming pursuit, but unlike patterning it has no compensating legacy in terms of improved scores or downed quarry. The reward of shot-speed testing is entirely in the realm of "knowing what's going on."

The two types of chronograph and what determines accuracy

Today’s electronic chronographs sense the passage of shot in one of two ways: either the pellets pass over photosensors which “see” the pellets as they go by, or they pass through a wire (or printed circuit) coil which responds to pellets' metallic mass and movement.

The photosensitive instrument is by far the more common: the Oehler, the ProChrono, and the Crony are examples of this type. Though it is often said that such chronographs measure the speed of the first pellet, it is probably safer to say that they measure some leading part of the charge. The results obtained from the photo-chronograph are good; they are especially impressive if you consider the portability and ease-of-use of some of the compact models.

Ballistic laboratories use “inductive” (also called coil) chronographs. Shotshell speeds quoted by manufacturers or reloading manuals are measured in this way. Here’s a much-condensed summary of the design and operation of this type of machine.

The sensors of the Oehler Model 71 Inductive Chronograph, the industry standard, are a pair of printed circuit boards rigidly mounted three feet apart. Each has a three-inch hole in its center through which the charge is fired. Each coil is part of an electronic circuit which tells a microprocessor when the shot charge *begins to leave* the hole it is passing through. The processor calculates the time that the shot was between the coils and displays the speed which that time represents.

The accuracy of a chronograph depends primarily on two factors. First, the distance between the sensors must be exactly known, and must not change between tests. This is no problem with one-piece units (ProChrono & Crony), but care must be taken with the multi-piece units (Oehler and others) to get the spacing and orientation precisely the same every time.

Second, the sensors must accurately and without variation locate the shot charge. If they can locate the pellets within 0.1 inch when the screens are 3 feet apart the reading will not be in error by more than 3 feet per second (fps). If the sensors are 1 foot apart, a 0.1 inch mistake results in a 10 fps error. This is the price paid by the one-piece units: shorter sensor-to-sensor distances require better optical performance. Coils are said to locate the shot charge to an accuracy of plus or minus 0.1 inches; over a 3- foot range that's about 6 fps with a 1200 fps load. My own tests support this claim. I've never seen any data on the ability of photosensors to accurately locate shot, and the early sections of this report is concerned with answering that question.

The demand for accuracy is amazingly high. Can the instruments we use really pinpoint, on a day in, day out basis, the location of equivalent parts of ill-defined clouds of shot within 0.1 inch when they are flying by at 1200 fps? The only way to find out if any particular device is doing what it promises is to run it through some tests.

I doubt that many users of chronographs ever actually put them through any systematic trials. Most buy the instrument, shoot some shots over it, and accept the results. More serious users calibrate with factory shells, perhaps assigning 1140 fps to the lights, 1200 fps to the heavies. I think this second group, in spite of their greater effort, is nearly as much in the dark as the first.

Test of increasing powder charges (1)

In order to have trust in a new scientific instrument you first have to see how it works when you know what the answers should be. How do you set up an experiment with a known outcome? I'll provide the evidence later that you can't use factory shells: their lot-to-lot consistency isn't good enough. Use instead a relationship we all know: when everything else is held constant, more powder results in more speed. If a chronograph works, it'll tell you that regularly increasing loadings result in regularly increasing speeds.

For each of the six chronographs in the test (two Oehler 35P's, a ProChronos Plus and Digital, a Chrony Alpha and an Oehler 71) a complete series of test shells was put together using a Redding Benchrest powder measure and a MEC Grabber for individual assembly. A series consisted of twenty shells each of seven loadings: 19, 19.5, 20, 20.5, 21, 21.5 and 22 grains of a popular powder selected for its ability to span a wide range of loadings without insufficient or excessive pressure. The test setup is pictured below.

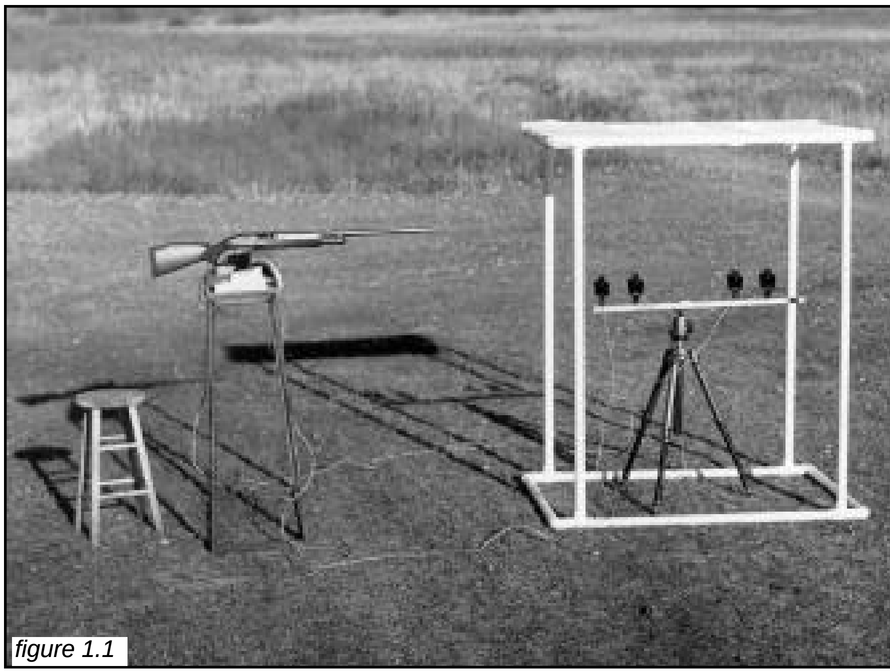


figure 1.1

A Remington 870 with a 30-inch, cylinder-choke barrel was fired from a rest aiming about eight inches over the down-range sensors. Two Oehler 35P chronographs (the duplication is to check for errors) were mounted on a square rod with holes accurately spaced to mount the "skyscreens," (Oehler's trade name for their sensors). The screen spacing for each chronograph was two feet. The measurement region for the first 35P started at 4 feet from the muzzle and ended at 6 feet; for the second it started and ended 6 inches farther along. A 3.5 by 5 foot diffuser was located about 30 inches above the sensors. All testing was completed within a couple of hours, with the loadings selected in random order. The setup for the other chronographs was similar; two chronographs were used at all times. The results are pictured below. Each dot represents the data-point from a single shot. In the cases where there are fewer than twenty dots there were duplicate speeds.

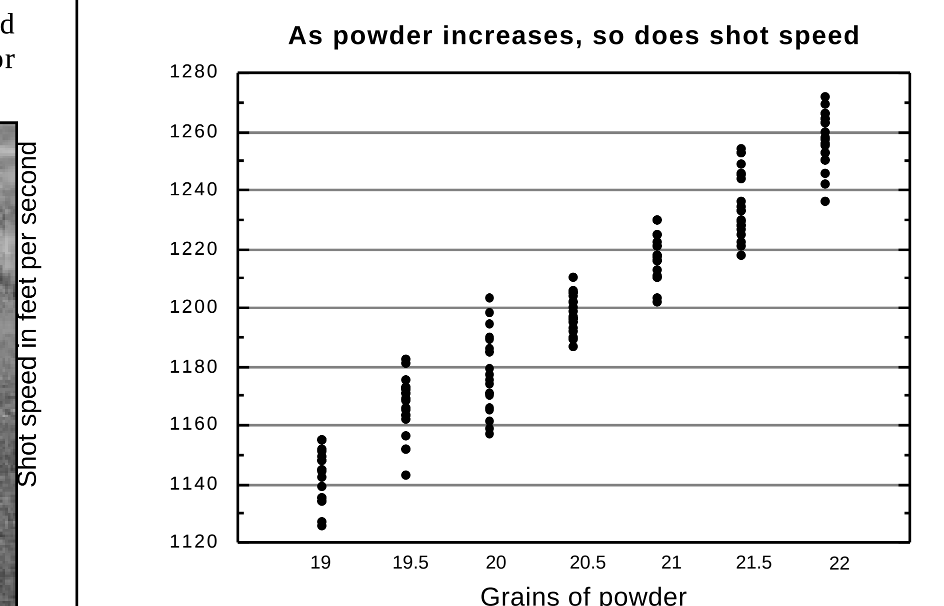


figure 1.2

When the loadings differ by 0.5 grain the speed distributions are clearly different, and when the spread is one grain there is no overlap at all. The results from all the other chronographs tested were similar. So far, we can say with confidence that they all are able to accurately track changes as small as one-half grain of this powder.

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Test of increasing powder charges (2)

The results of the previous test naturally lead us to the next question: "Just how small can powder changes go before a chronograph can't tell them apart?"

In this case the test sample consisted of six groups of ten shells each. The powder charges, individually weighed on a Denver Instruments A-500 scale, covered the range of 21.0 through 21.5 grains, with an increase of 0.1 grain at each step. The firing setup was the same as in the previous test, again using two Oehler 35P's. Later, the test was duplicated with an inductive Oehler 71.

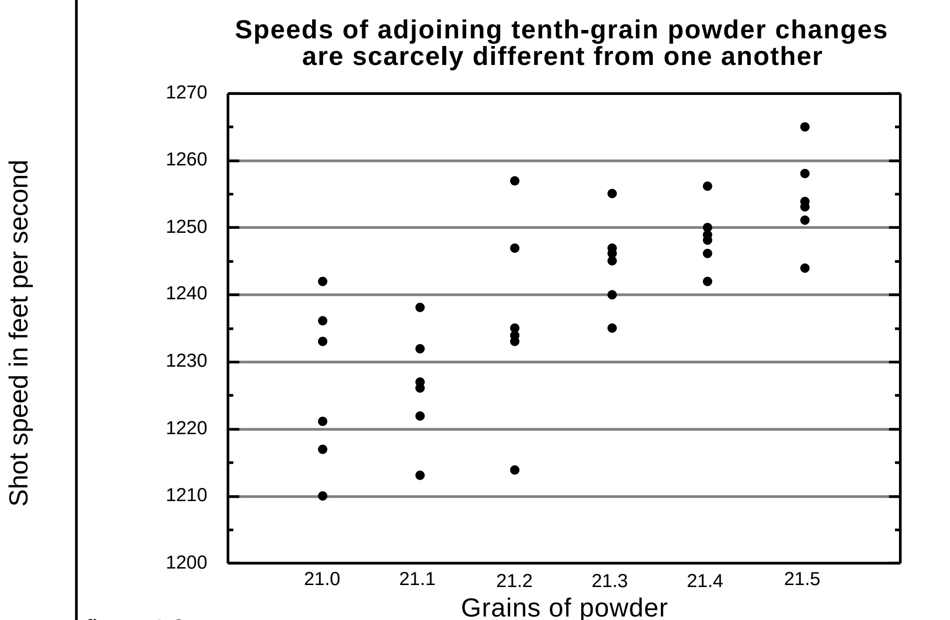

figure 1.3

As you scan across the data, you'll see that you have to span a range of 0.3 grains before you see a clear difference: the load with 21.3 grains is faster than the one with 21.0; 21.4 is faster than 21.1.

A simple statistical test, the "Sign Test," reports that half the differences of 0.2 grains are significant, as are all the 0.3 grain differences. None of the 0.1 grain differences are significant.

With the inductive Oehler 71 the speeds were higher, but otherwise the results were about the same. This is excellent performance from both types of chronograph. I did not test the other units but based on their results with 0.5 grain differences, I think all would accurately track differences of 0.2 to 0.3 grains of this powder.

And yet there is something about this graph that should give us pause—why aren't the speeds more consistent? We've kept everything constant, weighted every charge, tested all at one sitting, and yet we see the fastest and slowest shells at a particular loading often vary by 30 fps, in one case by 45. Is it the shells or the chronograph?

It's the shells. The two 35P's tracking together differed by no more than 4 fps on any shot; that means the "extreme" data points showed up on both of them. For the Model 71 there are two checks: pressure and gun movement. Both independent measures show that shells, no matter how carefully assembled, vary—this time by 40 fps, next time by 20, next time by …?

There is a limit to which increasing care is rewarded by increasing consistency; once you get the powder charges within 0.2-0.3 grains you hit a brick wall trying to get the speeds any closer. The whole used-hull / primer / powder / wad / assembly / chronograph system has enough variability built in to effectively put a ceiling on further improvement.

Prior to these tests I always used the Redding powder measure and MEC Grabber to make test loads, They were very good, but as figure 1.2 shows, still variable. In view of the apparent limit in consistency at about 0.3 grains, I wondered how my tired old MEC 9000H would stack up against the Redding-measured one-at-a-timers, since they both kept their charge-variations close to that one-third grain limit.

I matched the drop-weights of four MEC bushings to equal Redding-measured shells, and shooting twenty shells of each type I could hardly tell them apart. In three cases the individually measured shells were better, in one case the others, but the differences didn't amount to much and none was significant. With a progressive loader you can make so many more, and therefore test so many more, that the scale tips decisively to the production, rather than boutique, approach to loading. You'll get a more accurate picture of a load with two runs of 20 shots than one run of 10 weighed shells, and with an equal investment of time, with the progressive you'll have several boxes left over to shoot clay targets with.

What a typical test looks like

The previous graphs convey what may be a misleading picture of the orderliness of the data a chronograph provides. The numbers, as they appear one-by-one on the readout or printer, conceal the underlying trends within a jumble of random variation. What you end up with at the end of an experiment is a string of numbers on a slip of paper that you really hardly look at. You keep track of the summary statistics and the rest just gets “filed.” The following graph pictures the shots in the order in which they were fired using four types (Handicap, Heavy, Light, and “Lite”) of various brands of shells. Once again I used a cylinder-choked 870; the chronographs were again two Oehler 35P’s.

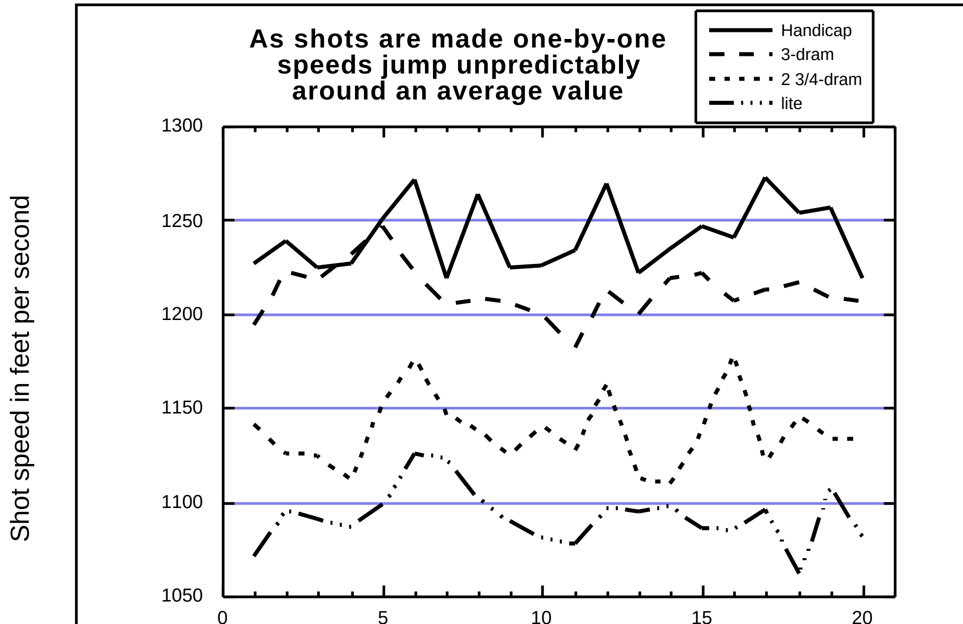

figure 1.4

Remember that this picture, chaotic as it is, is much more descriptive than a column of numbers. You can tell that there are four types of shells portrayed, but many other features of the test are lost in the “noise.”

The graph below is based on the same data as the previous one, but shows the speeds of each type of shell arranged from slowest to fastest. The slope of the line representing one type of shell is a measure of consistency of the speeds of each sample. A horizontal line would indicate complete consistency, all speeds the same—the more steep the slope, the greater the differences between shot speeds.

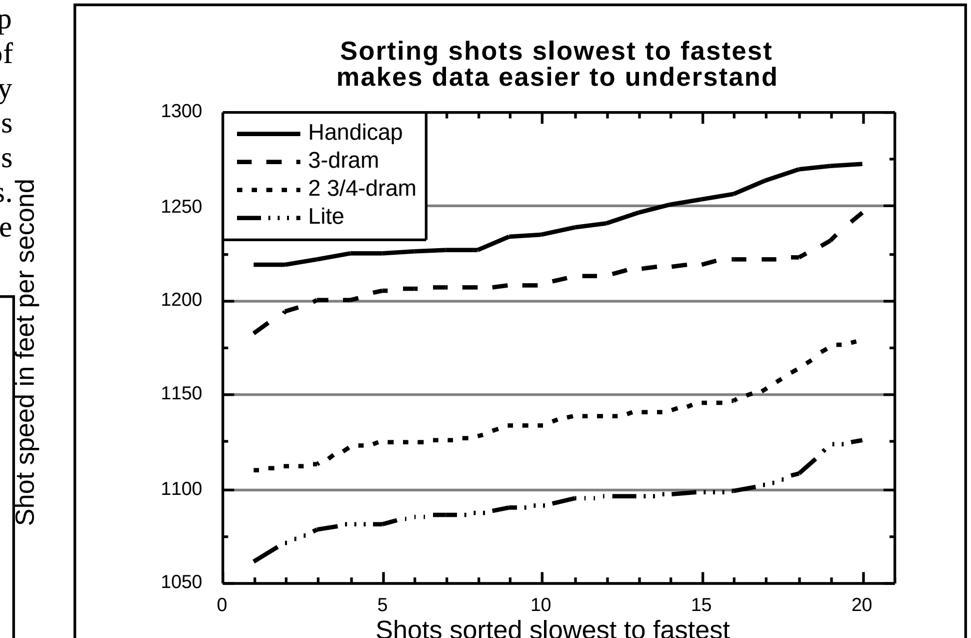

figure 1.5

This way of looking at the data not only lets you pick out the “average” (in this case the median, not the mean) as shot number 10 or 11, but also emphasizes the fact that most of the shells in a box are about the same (the broad, fairly flat mid-range of the lines) and that the extreme shells are not just an extension of the normal, but are in most cases a greater deviation than would be expected from looking at the rest.

How many shots are enough?

There are three statistics which characterize the results of a chronograph test. The first, average speed, needs little explanation. The average used is always the mean, obtained by adding up the values and dividing the total by the number of shots.

The second, extreme spread, is the difference between the fastest and slowest shots, and is only used because it's easy to calculate. Its weaknesses are that it is based entirely on extreme values and it is also strongly affected by the number of shots taken; the more you shoot, the likelier you are to run across an oddly fast or slow one.

The third, standard deviation, requires some further explanation. Standard deviation (SD) is a statistical measure of variability. For us, it is the way to describe the dispersion of speeds within a particular test. It is preferred to the extreme spread because (1) it is less affected by extreme values and the number of shots taken and (2) it offers a way to estimate how close the speed of this sample lies to the speed of the entire lot it was selected from. If we took ten shots and the average speed was 1200 with an SD of 10, we can be 90 percent confident that we'd get an average between 1196 and 1206 if we shot hundreds of them. You want low SD's; they are not only better statistical predictors, they represent better shells.

How many shots do you have to shoot to get a fair estimate of the average speed? Look back at figure 1.4. In all cases it's easy to find a string of 5 shots which is not representative of the rest of the shells, being mostly above or below the average. In contrast, almost every string of ten shots has both fast and slow shots and in equal proportion. And, in fact, experience tells me 10 shots is an adequate sample size, though I use 20 whenever I can.

I think that the question of how many shots you have to shoot to get a fair estimate of speed and variability is best answered by an illustrative experiment. I shot 100 shells using the two-Oehler-35P setup previously described. The ammo was a sample of very good reloads whose 100-shot average speed was 1221 fps and whose SD was 9. I then looked at successive 5,10, and 20 shot strings to see what I would have gotten if I had limited the test to that number of shells.

Within the twenty 5-shot strings, the maximum speed reported was 1237, the minimum was 1213. In other words they ranged from 16 fps too fast to 8 too slow. The SD's ranged from 6 to 14.

The 10-shot strings ranged from 1233 to 1215, a range of 12 too high to 6 too low. The SD's were from 6 to 11.

The 20 shot strings were most representative of the total 100. No average was more than 8 fps away from the mean, and all the SD's were within 2 of the overall value of 9. Although the results from 20 shots were best, I'm satisfied with 10. I'm not satisfied with 5.

The problem arises when the shells are less uniform. With an SD of 15 the standard deviation becomes annoyingly variable: It's 9 this time, 19 the next. What looked bad before may now look good, or vice versa. There's no way around this; it's in the math.

There remain three questions about the SD: 1) What should we call a particular SD: good, bad, or in-between?, 2) On what basis can we say that one load is more consistent than another? 3) What should we do with the information?

1) I've adopted some informal standards based on my testing: SD's of 11 or lower are good; those between 12 and 16 are average; higher numbers are below average. Incidently, the average SD for shells whose powder was weighed to the tenth of a grain was 8; the Redding and MEC products averaged about 9.

2) Dr. Ken Oehler included a "decision table" with the Model 33 literature. If ten shots are used and the SD of load "A" is 10 (good), load "B" is worse only if it's SD is greater than 18. That's a big difference. If you're comparing average loads with SD's between 12 and 16, the differences must be even greater, often over 25 in fact. Shooting more doesn't help much. The upshot is that the answer isn't worth the effort spent in getting it. Just call them both "average."

3) Rather than worry about "which is better" I think the shooter should simply set some standards. If your reloads don't register SD's under 11, change your technique or components until they do. If your factory shells aren't at least "average," switch to some that are.

Still, no matter how careful you are you are going to get some strange results. There's only one remedy: Do the test again.

Lighting and other details

All of the tested chronographs came with plastic diffusers and the advice to use them on cloudless days. I made my own, pictured in figure 1.1. The frame is 1-1/4 inch PVC tube with joints that slip together for transport; the canopy is white polyester. The setup is easy and I'd use nothing else.

A light meter says that this canopy, in the sun, is five times brighter than the blue sky above it. Surprisingly, it is also brighter than the sky on cloudy days. (The meter probably doesn't match the spectral sensitivity of the sensors, but this is at least a guide.)

Results are always better with a diffuser, be the day sunny or cloudy. The overall level of lighting is not important. On a not-so-bright day I used several layers of diffuser material to cut the light by 2/3 and all the instruments continued to work just fine, though the canopy, by this time, looked distinctly dark.

A distance of 4 feet from muzzle to first sensor was used except in the single case of the Crony measuring sub-sonic (Lite) loads. It had to be moved back to 6 feet to avoid just listing the speed of sound. The Oehlers became inconsistent much beyond six or seven feet.

Two more questions: Would the results have been different if I'd used a different distance? Can we measure the slowing of pellets as they get further from the gun?

For this experiment I used two ProChronos mounted on a long rod so the first sensor of the closer chronograph was 42 inches from the gun, the farther 72 inches. I measured the speed of 20 shots and the average for the ProChrono closer to the gun was 5 feet-per-second faster than the other. I then reversed the chronographs but the results didn't change—the faster one still measured faster, even though it was now farther from the muzzle than the other. Considering the uncertainly of speed measurements outlined earlier, I don't think you can successfully measure speed-loss over any distance you are likely to use with these chronographs.

There are two aspects of reliability which also must be addressed. The first is test/retest reliability. If you repeat a test on another day with everything set up anew, how close are the results to the ones in a previous trial? It was problems with test/retest reliability that led me to use two chronographs for all experiments reported here.

The ProChronos were excellent in this respect and the Crony almost as good. The Oehler 35P's were more of a challenge, though problems were almost always traceable to operator error. Their sensors must always be used in the same order, and be oriented in the same way. Turn one around and the speeds change. Replace a skyscreen with a new one and the speeds change. The "proof channel" (a third skyscreen) feature of the Oehlers had to be abandoned since it too often interfered with function of the main channel. This was likely due to the close screen spacing I used and the presence of a second 35P. Six screens in a space of 30 inches was just too much electrical confusion for the units to sort out. The Crony usually measured 15 fps faster than the others

The reliability of the chronographs themselves was also a problem. The experiment started with seven instruments. Four had to be returned to their makers for repairs unrelated to hitting them with shot; one brand never worked reliably in spite of repairs and had to be eliminated from the tests.

Summary of Section 1

In this section I discussed the two types of chronograph, the light sensitive type for consumer use and the inductive type used by ammunition manufacturers. Both types were able to distinguish speed differences in shells differing by only 0.2 or 0.3 grains in charge weight. Attempts at producing super-consistent shells by weighing powder to the tenth of a grain proved fruitless.

Shot speed varies erratically from round to round; 10 shots is about the minimum sample which will give useful results in either average speed or variability. Twenty shots give a more representative picture of the entire lot and were used in these tests when possible.

Variability is measured by standard deviation (SD), and smaller values denote more consistent shells. Standard deviations of 11 or below are desired but 17 or less will do.

A diffuser over the chronograph improved results under all lighting conditions. Small differences in distance from muzzle to chronograph don't affect results.

The next installment of this report will outline the results of tests on factory shells, the problem of errors, and the effects of bore and choke on measured speed.

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