System 89 Preliminary

The System 88 has provided much insight into the exterior ballistics of small arms, but at a price. The ’88 relies on the older System 86 developed to meet military test needs on a proving ground. High precision with long range were absolute requirements. The ’86 delivers microsecond time accuracy and centimeter target accuracy when used with up to ten targets spread over ranges of many miles. The ’88 delivers similar accuracy for three targets spread over a few kilometers. The ’88 inherited the use of GPS timing reference and flexible radio network from the ’86.

Firing data collected with the System 88 has validated several premises.

1. Exterior ballistic prediction models based on muzzle velocity are valid if, and only if, the predicted time-of-flight matches observed time-of-flight at long range.
2. Long-range behavior is primarily governed by time-of-flight, not distance traveled.
3. Accurate long-range predictions must be based on accurate measurements of long-range time-of-flight.
4. The combined barrel/bullet system must be considered. The ballistic coefficient and drag function depend on both barrel and bullet.

After using the instrumentation and interpreting the resulting data, we’ve determined realistic expectations of the accuracy required.

1. Muzzle velocities should be measured to an accuracy of 0.1 percent. This accuracy is approached with Skyscreen III units spaced at 9 feet. SAAMI specs require a spacing of 20 feet with a tolerance of 0.25 inch; that’s 0.1 percent.
2. Distance to target should be measured to 0.1 percent. That’s 1 meter in 1,000 meters or 0.5 meter in 500 meters. This accuracy is claimed by many laser rangefinders, but has only been proven using an appropriate target and with selected rangefinders such as those modified by Leupold, tested by Downrange Farms, and available from Oehler.
3. The time-of-flight to target should be measured to an accuracy of 0.1 percent. Ballistic coefficient is computed from muzzle velocity, distance-to-target and time-of-flight. If you expect any chance of computing ballistic coefficient to near one percent, you must know all the inputs to better than 0.1 percent.

If all your measurement accuracies are within the suggested 0.1 percent limits, then you can reasonably expect that your drop predictions might be as close as 0.1 mil. This prediction falls within the range normally attributed to component variation of individual loads and the ability of the shooter.

After several years using the ’88 and analyzing the collected data, we can revisit the design of the system. We conclude that the ’88 is too much like its big brother ’86; it is an over-kill. The use of Skyscreen III units with nine-foot spacing is appropriate for muzzle velocity. The use of the modified Leupold rangefinder with appropriate reflective target provides distance to better than tenth percent. The measurement of flight times to microsecond accuracy is excessive. At the longer ranges typically encountered in long-range shooting, flight times are typically greater than one second and accuracy to one millisecond is adequate.

It is recognized that most exterior ballistic predictions have been based on the assumption that behavior depends only on muzzle velocity, atmosphere, assumed drag function, and ballistic coefficient. It has always been assumed that the ballistic coefficient is independent of the barrel from which the bullet is fired. We built the System 88 under the premise that a few facilities would use the system to test various bullets, and that the resulting ballistic coefficients (and drag functions) could be distributed to many users of these bullets. This expected sale of only a few systems dictated a high per-system price.

The need for testing individual rifle/ammo pairs has since been demonstrated as essential to accurate predictions. We must produce a capable system at a price within reach of individuals or small groups. Consider where the cost and complexity of the System 88 can be pruned.

1. The requirement for multiple downrange targets is appropriate for the proving ground. They can place acoustic target arrays atop 90-foot poles to catch high midrange trajectories. Most rifle shooters can't do that; they need only one target at long range. A simple one-link radio pair can replace the complex radio network.
2. One microsecond timing accuracy requires GPS timing. Millisecond timing accuracy is adequate for finding ballistic coefficients measured over long range. It appears that downrange timing can be synchronized to better than one millisecond with a simple "one link" radio protocol. Microsecond accuracy between event times at the target can be retained for muzzle velocity and target scoring. The complexity, nuisance, power drain, and expense of the GPS is eliminated.

The conceptual design of the System 89 begins.

1. The new system will use XBee Pro 900HP radio modules. The 2.4 GHz XBee Pro radios of the '88 are marginal at the longer ranges now expected. The requirement for an external antenna for longer ranges may remain, therefore use the RPSMA antenna connector. Instead of the convenient DigiMesh network of the '88, the radios must use a rigid and more predictable protocol. To eliminate the GPS requires that we maintain repeatable latency to establish adequate time synchronization between gun and target timers.
2. The large 12-volt gel-cell battery can be replaced with a single 18650 lithium 3.7-volt cell. FTDI now produces an USB-to-serial IC that includes controls for a battery charging circuit. This will allow convenient battery charging from a USB source or from a common cell-phone charger. Rough estimates of power include 30 ma for radio and 30 ma for processor at near battery voltage. A small 3-to 9-volt converter will be required for skyscreens and linear circuits; estimate 30 ma from battery for this. Average battery current should be approximately 100 ma.
3. The firing line controller will be connected to the PC with a USB A-to-B "printer" cable. This eliminates the need for the "Green Stick" radio at the PC. It also avoids the fragile USB A to micro cable used on cell phones.
4. A microcontroller must provide the event timing, connect to the radio, and connect to the PC. The Netburner module used in the '88 consumes significant power. The replacement should include two serial ports (radio and PC), at least four timers, and require minimal power. The chosen

microcontroller must have robust support including a common higher level language and convenient debugging facility. The person doing the required firmware must have a significant voice in the selection of specific microcontroller.

5. The required firing line and target controllers will be identical. They can probably be in a simple metal case not much larger than the System 36. All components, including battery, can be mounted on a single board.
6. The operator interface and software of the ’88 will be retained. It is anticipated that the communication and control protocols of the ’88 will be retained to the maximum practical extent considering the change from DigiMesh to AT or API protocols. Software must include provision to “pair” controller radios; this can be done “over the air” or as a separate step using the USB port.
7. The downrange target functions will include square and flyover acoustic targets along with an impact array for subsonic. The impact array is primarily for TOF measurements but may provide coarse target information. Use of targets larger than a 4x8 plywood sheet may be allowed, but will not be encouraged. One specific 4-mic asymmetric arrangement will probably be suggested for impact targets requiring target indication. All impact arrays will default to using “first mic” as TOF stop even if targeting fails.
8. It is desired that a single controller with skyscreens have the capability to operate as a chronograph at the muzzle.
9. Pending further tests of the solver, it is possible that the asymmetric microphone array might allow both downrange targeting and remaining velocity estimates of supersonic bullets without measuring muzzle velocity, range, or time-of-flight. (We must provide air temperature or otherwise estimate Mach speed.)
This is still a definite maybe!