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Michael Riley,[1] Dwight Barry,[1] and Nicholas G. Paulter[2]

Redundant Ballistic Chronograph Configuration for Body Armor Testing

Reference

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ABSTRACT

A new configuration of the light screen pairs used in a redundant ballistic chronograph is described. This configuration complies with current ASTM International and National Institute of Justice requirements for measuring the ballistic performance of body armor. Although it currently requires dismantling the commercially available light screens and installing them on custom-made mounting frames, the overall configuration is simpler to arrange and to obtain separation uncertainties than the conventional configuration that uses separate mounting frames.

Keywords

armor, ballistic measurement, body armor, bullet velocity, chronograph, light screen, velocity

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[1] Material Measurement Laboratory, National Institute of Standards and Technology, 100 Bureau Dr., Gaithersburg, MD 20899, USA, https://orcid.org/0000-0003-4242-4883 (M.R.), https://orcid.org/0000-0002-4229-6642 (D.B.)

[2] Material Measurement Laboratory, National Institute of Standards and Technology, 100 Bureau Dr., Mail Stop 8102, Gaithersburg, MD 20899, USA (Corresponding author), e-mail: nicholas.paulter@nist.gov, https://orcid.org/0000-0002-9782-0894

Introduction

Measuring the velocity of the bullets that impact body armor and the mass of those bullets are two factors that are used in evaluating the ballistic performance of body armor worn by law enforcement and military personnel. Particular ballistic test threats (caliber, mass, and velocity) have been defined by the National Institute of Justice (NIJ) in NIJ–0101.06, *Ballistic Resistance of Body Armor*,[1] for assessing the ballistic-resistance performance of law enforcement body armor, and it is these threats that are used to qualify armor in the NIJ body armor program. Laboratories that test body armor must be able to accurately estimate the bullet velocity during ballistics tests.

The most common method of measuring bullet velocity in commercial laboratories is a system of commercial light screens and chronographs. Two independent sets of instrumentation, as required by test standards, are typically used. Each set includes a chronograph, or other timing device, and two light screens. When a projectile is fired, the timing device will measure the time interval between the two timing-event signals, one from the first, or *start*, light screen and one from the second, or *stop*, light screen. This time interval is used to compute the projectile velocity. Because the projectile timing is measured at only two planes, defined by the light screens, the estimated velocity is the average velocity during the interval that the projectile is traveling between the two light screens, which is approximately the velocity at the center of the projectile's path between the light screens.

To meet the standard requirements[1,2] for two independent sets of instrumentation, two chronographs and four light screens (two pairs) are necessary. Because the light screen frames have a finite width, when commercial light screens are used in their normal configuration, there must be either an offset between the two pairs or a different spacing between the pairs, as shown diagrammatically in **figure 1**. The configuration of each pair being staggered, that is, having the same spacing with a displacement offset between the pairs, as described in **Table 1**, was often used prior to the current NIJ standard, NIJ–0101.06,[1] but this configuration resulted in differences in the estimated projectile velocities from the two chronographs, due to the measurement locations being different distances from the test article. The configuration of each pair having different spacings, with the second pair nested between the first pair, is used to meet the current standard requirements.[1,2] This second configuration reduces the differences in the estimated projectile velocities between the two chronographs but results in each measurement having a different uncertainty. This difference will be due to how the velocity uncertainty is a function of the distance between the light screens, the uncertainty in the distance measurement, the time of flight between the screens, and the uncertainty in the time measurement (see equation (2) and explanation of this equation later in this document). In both configurations, laboratories generally mount both start screens to a common support, and similarly, both stop screens are mounted to a different common support.

NIST has developed a new configuration, modifying a set of commercial light screens such that two screens may be co-located (see **fig. 2**). This revised configuration allows both pairs of screens to have the same spacing and measurement uncertainty while simplifying the arrangement of the instrumentation in the laboratory.

FIG. 1
Traditional configuration of the light screens of a two-chronograph system.

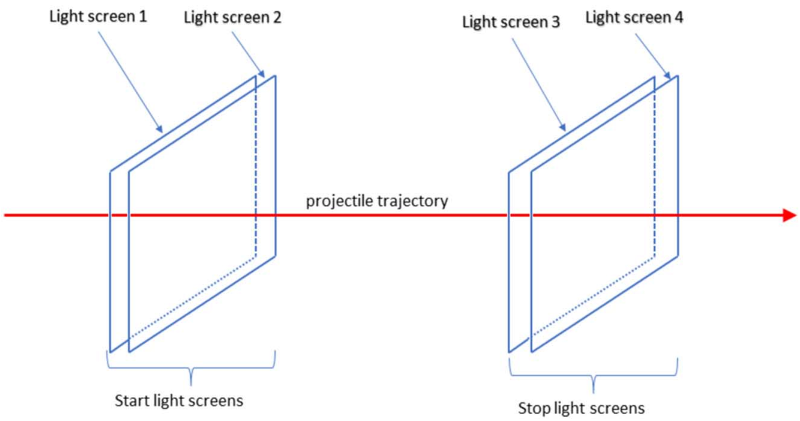
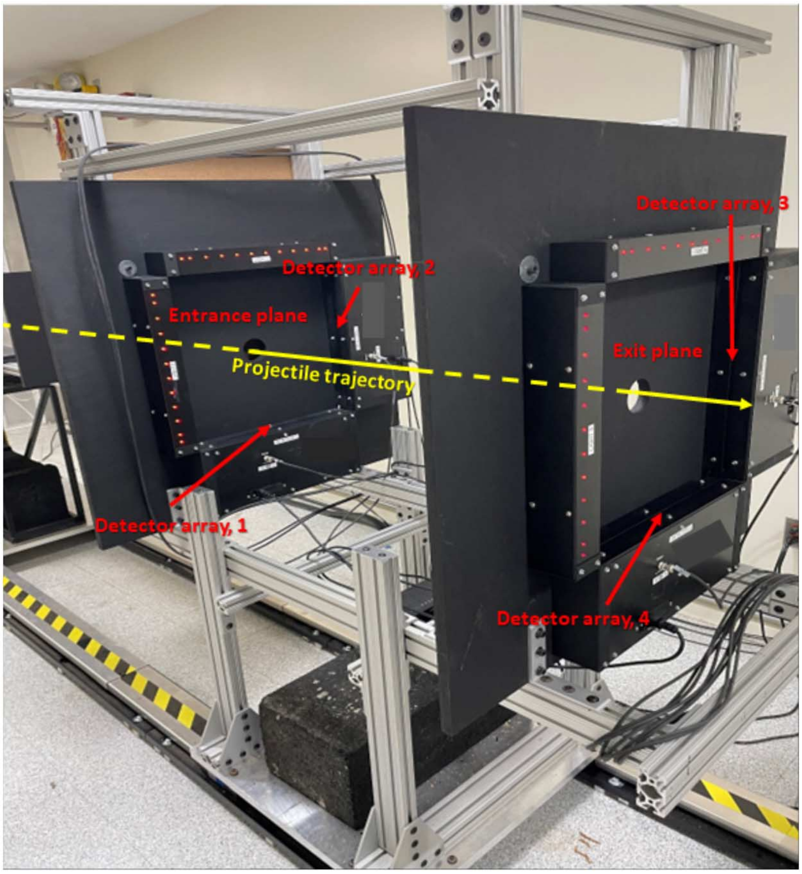


TABLE 1
Light screens associated with chronographs for different dual-chronograph configurations (see **fig. 1**)

	Chronograph Designation	Light Screen Paired in Chronograph
Staggered configuration	Chronograph 1	Light screen 1 paired with light screen 3
	Chronograph 2	Light screen 2 paired with light screen 4
Nested configuration	Chronograph 1	Light screen 1 paired with light screen 4
	Chronograph 2	Light screen 2 paired with light screen 3

FIG. 2

Image of double chronograph configuration with two light screens in the start plane and two light screens in the stop plane.



Background

The past versions of the NIJ standard for assessing the performance of ballistic-resistant body armor,[3,4] the current version (NIJ–0101.06[1]), and the ASTM specification for ballistic test, ASTM E3062/E3062M-20, *Standard Specification for Indoor Ballistic Test Ranges for Small Arms and Fragmentation Testing of Ballistic-Resistant Items*, all require two independent velocity measurement systems to estimate the velocity of the test projectiles. The pending version of the NIJ body armor standard,[5] which is currently in draft form, is expected to reference the aforementioned ASTM specification to set the velocity measurement requirements. These standards allow for velocity measurement systems using a variety of different technologies, such as light screens, break screens, or laser break beams combined with appropriate timers; radar systems; or imaging systems, such as flash X-ray imaging or high-speed optical photography. For a variety of reasons, including ease of installation, flexibility in use, and relatively low cost, the most commonly used technology is commercial light screens combined with digital chronographs or frequency counter-timers. Waveform recorders may also be used to measure the time of flight; however, these are not commonly used in commercial ballistic testing laboratories.

The current tolerance requirement for bullet velocity in NIJ–0101.06[1] is 9.1 m/s. Furthermore, the standard requires that two (or more) measurements be made using instrumentation sets that are independent of each other and that these measurements not differ by more than 3 m/s. When these conditions are met, the reported velocity is the mean of the velocity measurements. The standard also requires that the combined uncertainty of the velocity measurements from the different instrument sets is less than 1.0 m/s[1].

The chronograph, or timer, itself only provides a time interval measurement for the calculation of velocity. The chronograph relies on signals from two independent light screens, or other detectors, which will produce an electrical pulse or change the state of a binary signal at the instant that the test projectile passes through the detector. Estimation of the projectile velocity requires an accurate measurement of the distance between the two detectors, the travel time of the bullet between the light screens, and an estimation of the measurement uncertainties associated with the distance and time measurements.

Light screens basically provide a sheet of light through which the projectile passes. The light may be provided by a single linear incandescent bulb, an array of lenses that focuses the ambient light, or a linear array of light-emitting diodes (LEDs). Screens that use visible light tend to be easily triggered by reflected light or by changes in the ambient lighting, so laboratory quality commercial light screens generally use an array of infrared LEDs, which are mounted on one side of the light screen. On the opposite side of the light screen is mounted a linear array of diode light detectors. When the projectile passes through the light screen, it blocks some of the light to one or more detectors, which triggers the generation of an electrical pulse that can be detected by a chronograph or other device.

As described here, four light screens (arranged in two pairs) are necessary to meet standard requirements for two independent sets of instrumentation. Because the width of the most commonly used commercial light screens is approximately 7 cm, the distance between the sensors for the inner pair of light screens will be at least 14 cm less than the distance for the outer pair. This results in the measurement uncertainty being slightly greater for the inner pair of light screens in the nested configuration.

Because the estimation of the projectile velocity is an indirect measurement, it is necessary to consider the uncertainties from each of the measurements that can be made directly and to use the law of propagation of uncertainty[6] to calculate the combined standard uncertainty. The relationship between the estimated velocity and the two measured quantities is defined as follows:

$$v = \frac{d}{t_d} \tag{1}$$

with v representing the estimated projectile velocity, d representing the estimated distance, or separation, between the detection points on the start and stop screens, and t_d is the delay between stop and start timing events that represent the estimated time of flight for the projectile between the two screens. Using the law of propagation of uncertainty, and assuming that the measurements of the distance and time are completely independent, which will lead to the estimated covariance being zero, the uncertainty of the velocity estimate has been shown to be as follows[7–9]:

$$u_c(v) = v\sqrt{\frac{u_d^2}{d^2} + \frac{u_{t_d}^2}{t_d^2}} \tag{2}$$

Here, $u_c(v)$ represents the combined standard uncertainty of the velocity estimate, and u_d and u_{t_d} represent the estimated uncertainties of the measurements of d and t_d. The t_d is computed using

$$t_d = t_{\text{stop}} - t_{\text{start}} \tag{3}$$

where t_{stop} is the reference instant for the stop event (the pulse from the stop light screen), and t_{start} is the reference instant for the start event (the pulse from the start light screen). The reference instants are instants that the pulse exceeds a reference level of the pulse, such as a level corresponding to 50 % of the pulse amplitude. Detailed explanations of the components are given in other works.[7–9] Factors contributing to the uncertainty in the distance estimation include errors in the distance measurement, misalignment of the screens from parallel to each other, misalignment of screens from perpendicular to the projectile's line of flight, projectile yaw (the rotation of the axis of symmetry of the projectile relative to its direction of travel), and changes in the screen spacing due to temperature fluctuations. When these individual components are not correlated, the root-sum-of-squares method may be used to combine them into a single uncertainty value.[6]

New Configuration

The new configuration for the light screens, although implemented here for only two ($N = 2$) light-screen pairs, may include more than two light screens at either the start or stop screen locations (as shown diagrammatically in fig. 3). This new configuration was conceptualized to address the requirements of the NIJ–0101.06[1] for the placement of the light screens such that both pairs are centered at the same location along the projectile trajectory while still allowing both pairs to have the same separation between light screens.

Analysis of historical data compiled by NIST from around 2007 to 2012 using a conventional staggered screen configuration showed that out of 3,653 shots, 1,292 (35 %) had absolute differences of 1.0 m/s or more between the two velocity measurements. These data, plotted in figure 4, included shots with three different calibers of bullet (9 mm, 357 Magnum, and 44 Magnum), and with estimated velocities from 262 m/s to 627 m/s, where this estimate is the average of the velocities measured by the two chronographs. The frequency distribution of the differences in the measurements is shown in figure 5. The standard deviation of these differences was 1.61 m/s, which can be considered as the combined instrumental uncertainty for two separate instruments.

FIG. 3

New configuration of light screens. The new configuration allows more than two co-located light screens for either the start or stop locations.

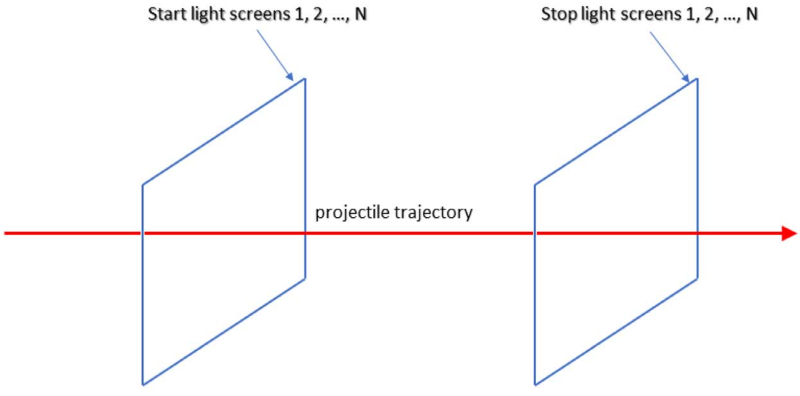


FIG. 4

Recorded differences from 3,653 shots versus estimated velocity.

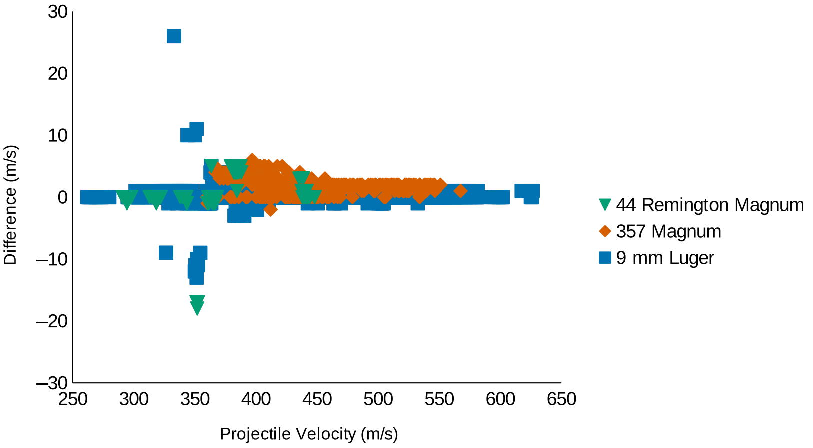
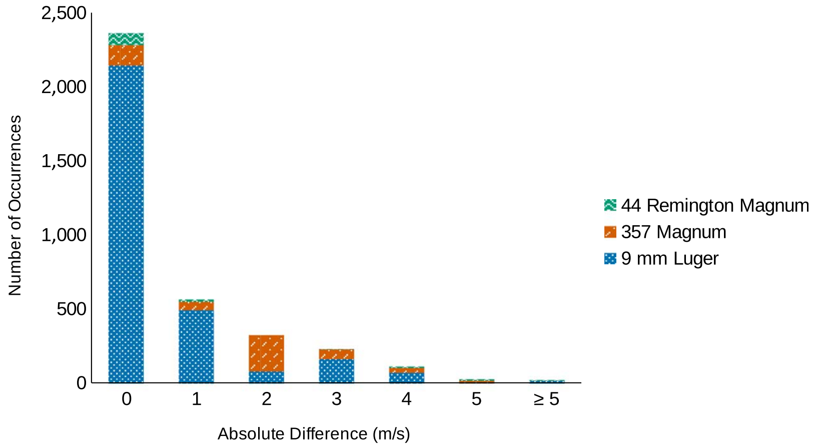


FIG. 5

Frequency of occurrence of the velocity differences in the historic test data (see fig. 4). Not shown are the results from the 22 shots in the historic test data that had differences greater than 6 m/s.



Using the assumption of a normally distributed response, with the uncertainty of each chronograph-light-screen system being independent, the combined instrument uncertainty is the square root of the sum of the squares of the two individual instrument uncertainties. Because both sets of instrumentation use similar components, the uncertainties associated with each set should be approximately equal; therefore, the individual instrumental certainty can be estimated as the combined instrumental uncertainty divided by the square root of 2. This velocity difference results in an instrumental uncertainty for this historical data for a single chronograph of approximately of 1.14 m/s, which is greater than the 1.0 m/s allowed by the NIJ–0101.06.[1] However, recent observations at NIST during 2021 and 2022 for a staggered configuration have demonstrated a velocity difference between the two chronographs of nominally 3 m/s to 4 m/s, which is compared directly with the results presented herein.

Consequently, we designed a new configuration that was based on the components (specifically, the light sources and the linear detector arrays) of commercially available light screens. These components were mounted to provide two start light screens at one common plane and two stop light screens at another common plane (see fig. 2).

The mounting structure for the light sources and detector arrays serves three functions. One function is the obvious structural support of the light sources and detector arrays. Different materials were considered for the mounting structure, including wood-based products and non–wood-based products. Wood products, and not metal or plastic, were selected to help minimize the propagation of pressure waves between the start and stop planes and, thus, reduce the probability of false triggering by the pressure waves. The mounting structure also provides a well-defined reference surface for measuring the separation between the detector arrays of the start and stop planes, and this facilitates the adjustment of the parallelism between the start and stop planes. The mounting structure, as designed here, also acts as a blast shield. The necessity of a blast shield became obvious when velocities of subsonic projectiles were erroneously measured to have nominally sonic velocities. This problem occurs for subsonic projectiles in which the ejecta travels faster than the projectile. These aberrant velocities are caused by ejecta from the muzzle blast that occludes the light to the detector arrays. Although a blast shield is placed near the muzzle, aberrant sonic velocities of subsonic projectiles were still observed, though not as often as without this blast shield. The secondary blast shield incorporated into the mounting structure effectively eliminated the remaining aberrant sonic velocity measurements.

A four-channel waveform recorder is used to capture the waveforms generated by the light screens (see fig. 6). Each light screen output is connected to an electrically independent channel of the waveform recorder. Consequently, a single shot will trigger the acquisition of four independent waveforms (as shown in fig. 6). A valid shot is obvious from the waveform recorder data if all four channels of the waveform recorder display a rectangular pulse waveform, similar to those shown in figure 6. Furthermore, the waveforms captured by the waveform recorder may be used to perform a detailed velocity measurement uncertainty analysis.

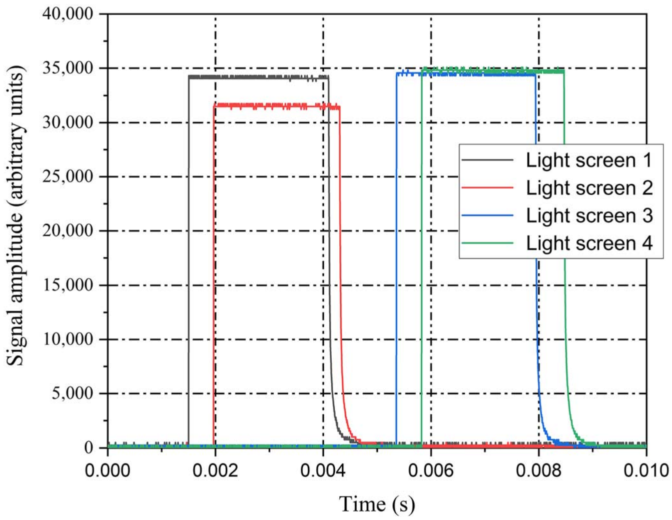


FIG. 6 Four step-like pulse waveforms, one from each light screen, as captured by a waveform recorder. To clearly display the four unique waveforms, these waveforms were captured using the conventional staggered light-screen configuration (see Table 1).

Results

The separation between the muzzle and the first (start) light screens was approximately 2 m. The separation, d, between the start light screens and the stop light screens was adjusted to be nominally 1 m. After this adjustment, d was verified by measuring the separation between each of the four corners of the light screen mounts using two different tape measures by two different people. This resulted in 10 measurements per corner with $d = 1.00$ m and $u_d = 0.001$ m. This u_d includes the standard uncertainty of the measurement of d, instrumental uncertainty, and operator uncertainty. The value of u_d is dominated by operator uncertainty and instrumental uncertainty, because the resolution of the tape measures (the instruments) used is 1 mm.

The t_{start} and t_{stop} for all four light screens as well as the delay, t_d, between the stop and start light screens for both chronographs was measured for three bullet types of two different bullet calibers (357 Magnum jacketed soft point [JSP]), 44 Magnum jacketed hollow point [JHP], and 44 Magnum JHP with alternative propellant), and the values were recorded using a waveform recorder. Table 2 shows the results of a representative set of these t_{start} and t_{stop} for the two start and the two stop light screens. The standard deviation of the start instants is shown at the bottom of columns 2 and 3 (number starting from leftmost column). The standard deviation (standard uncertainty) in t_{start} and t_{stop} is around the same value as the resolution of the timebase of the waveform recorder, which is 4×10^{-6} s for the timebase settings used. This table also shows the t_d measurements from the four possible pairings of light screens, with the two rightmost columns showing the average and standard deviation for these four t_d measurements, where the standard deviation is approximately that same as u_{t_d}, which is approximately 7.7×10^{-6} s.

There are six ways of computing the differences, Δt_d, between the four t_d values, which gives 90 values for the three different bullet types and the five shots conducted for each bullet type.

The delay difference, Δt_d, is obtained for two chronographs, A and B, where Chronograph A comprises light screens 1 and 3 and Chronograph B comprises light screens 2 and 4 (where the pulses from these light screens, from which t_{start} and t_{stop} are obtained, are shown in fig. 6). This delay is computed using the following equation:

$$\Delta t_d = |t_{d,A} - t_{d,B}| \tag{4}$$

where $t_{d,A}$ and $t_{d,B}$ are the delays measured using Chronograph A and Chronograph B, and $|x|$ returns the absolute value of its argument x.

TABLE 2

Results of timing measurements taken using an oscilloscope

	$t_{start,A}$ Start Time, s	$t_{start,B}$ Start Time, s	$t_{stop,A}$ Stop Time, s	$t_{stop,B}$ Stop Time, s	$t_{start,A} - t_{start,B}$, s	$t_{stop,A} - t_{stop,B}$, s	t_d (A,A), s	t_d (B,B), s	t_d (A,B), s	t_d (B,A), s	Average, s	Std. Dev., s
44 Magnum,	1.50E-03	1.49E-03	3.81E-03	3.81E-03	1.20E-05	0.00E+00	2.31E-03	2.32E-03	2.32E-03	2.31E-03	2.31E-03	6.00E-06
JHP,	1.50E-03	1.49E-03	3.83E-03	3.83E-03	1.60E-05	0.00E+00	2.32E-03	2.34E-03	2.34E-03	2.32E-03	2.33E-03	8.00E-06
AltP	1.50E-03	1.49E-03	3.79E-03	3.79E-03	1.20E-05	0.00E+00	2.29E-03	2.30E-03	2.30E-03	2.29E-03	2.29E-03	6.00E-06
	1.50E-03	1.49E-03	3.82E-03	3.82E-03	1.60E-05	0.00E+00	2.32E-03	2.33E-03	2.33E-03	2.32E-03	2.32E-03	8.00E-06
	1.50E-03	1.49E-03	3.79E-03	3.79E-03	1.20E-05	−4.00E-06	2.28E-03	2.30E-03	2.30E-03	2.29E-03	2.29E-03	6.32E-06
357 Magnum	1.50E-03	1.50E-03	3.82E-03	3.82E-03	0.00E+00	0.00E+00	2.32E-03	2.32E-03	2.32E-03	2.32E-03	2.32E-03	0.00E+00
JSP	1.50E-03	1.50E-03	3.77E-03	3.76E-03	0.00E+00	4.00E-06	2.26E-03	2.26E-03	2.26E-03	2.26E-03	2.26E-03	2.00E-06
	1.50E-03	1.51E-03	3.76E-03	3.76E-03	−4.00E-06	0.00E+00	2.26E-03	2.25E-03	2.25E-03	2.26E-03	2.25E-03	2.00E-06
	1.50E-03	1.50E-03	3.76E-03	3.76E-03	0.00E+00	0.00E+00	2.26E-03	2.26E-03	2.26E-03	2.26E-03	2.26E-03	0.00E+00
	1.50E-03	1.51E-03	3.79E-03	3.79E-03	−4.00E-06	0.00E+00	2.28E-03	2.28E-03	2.28E-03	2.28E-03	2.28E-03	2.00E-06
44 Magnum,	1.50E-03	1.50E-03	3.89E-03	3.89E-03	8.00E-06	−3.00E-06	2.39E-03	2.40E-03	2.39E-03	2.39E-03	2.39E-03	4.27E-06
JHP	1.50E-03	1.49E-03	3.87E-03	3.88E-03	1.60E-05	−4.00E-06	2.37E-03	2.39E-03	2.38E-03	2.37E-03	2.38E-03	8.25E-06
	1.50E-03	1.49E-03	3.87E-03	3.87E-03	1.60E-05	0.00E+00	2.37E-03	2.38E-03	2.38E-03	2.37E-03	2.38E-03	8.00E-06
	1.51E-03	1.49E-03	3.88E-03	3.88E-03	1.30E-05	0.00E+00	2.38E-03	2.39E-03	2.39E-03	2.38E-03	2.39E-03	6.50E-06
	1.50E-03	1.49E-03	3.86E-03	3.86E-03	1.40E-05	−4.00E-06	2.36E-03	2.37E-03	2.37E-03	2.36E-03	2.37E-03	7.28E-06
Average	1.50E-03	1.50E-03										
Std dev	2.49E-07	7.45E-06										

Note: Shown are the start and stop instants for Chronograph A ($t_{start,A}$ and $t_{stop,A}$) and Chronograph B ($t_{start,B}$ and $t_{stop,B}$), the difference between the start and stop instants, and the t_d between different start and stop light screens. For example, t_d (A,A) is the delay between the start and stop screens of Chronograph A. The average and std dev columns apply to the t_d columns. All of the 44 Magnum bullets used were a jacketed hollow-point style with a nominal mass of 15.5 g, and all of the 357 Magnum bullets used were a jacketed soft-point style with a nominal mass of 10.2 g. AltP indicates an alternate propellant (gunpowder) was used.

Table 3 shows that the differences, $t_{stop,A} - t_{stop,B}$, in the stop reference instants (where $t_{stop,A}$ is provided by the pulse from the second light screen of Chronograph A, namely light screen 3, and $t_{stop,B}$ is provided by the pulse form the second light screen of Chronograph B, namely light screen 4, where these pulses are shown in fig. 6) are not dependent on bullet type and are much less than u_{t_d}, which is 7.7×10^{-6} s. This is not the case for the

TABLE 3

The $t_{start,A} - t_{start,B}$, $t_{stop,A} - t_{stop,B}$, and Δt_d for the different measurements

	$t_{start,A} - t_{start,B}$		$t_{stop,A} - t_{stop,B}$		Δt_d	
	Average, s	Std. Dev., s	Average, s	Std. Dev., s	Average, s	Std. Dev., s
All	8.41E-06	6.48E-06	1.12E-06	1.74E-06	6.87E-06	6.43E-06
44 Magnum	1.35E-05	2.50E-06	1.50E-06	1.86E-06	9.50E-06	6.26E-06
357 Magnum	1.60E-06	1.96E-06	8.00E-07	1.60E-06	1.60E-06	1.96E-06

Note: The average and standard deviation for the 90 possible values of Δt_d are shown in the two rightmost columns, and the other columns show the average and standard deviation for the differences between t_{start} and $t_{stop,}$ for the two start and the two stop light screens.

TABLE 4

Velocity values for the different bullets and pairings of light screens

	Velocity Start A, Stop A, m/s	Velocity Start B, Stop B, m/s	Velocity Start A, Stop B, m/s	Velocity Start B, Stop A, m/s	Velocity Average, m/s	Velocity Std. Dev., m/s
44 Magnum,	4.33E+02	4.31E+02	4.31E+02	4.33E+02	4.32E+02	1.12E+00
AltP	4.30E+02	4.27E+02	4.27E+02	4.30E+02	4.29E+02	1.47E+00
2 m	4.37E+02	4.35E+02	4.35E+02	4.37E+02	4.36E+02	1.14E+00
	4.32E+02	4.29E+02	4.29E+02	4.32E+02	4.30E+02	1.48E+00
	4.38E+02	4.35E+02	4.36E+02	4.37E+02	4.36E+02	1.20E+00
357 Magnum,	4.31E+02	4.31E+02	4.31E+02	4.31E+02	4.31E+02	0.00E+00
JSP	4.42E+02	4.42E+02	4.42E+02	4.42E+02	4.42E+02	3.91E-01
2 m	4.43E+02	4.44E+02	4.44E+02	4.43E+02	4.44E+02	3.94E-01
	4.43E+02	4.43E+02	4.43E+02	4.43E+02	4.43E+02	0.00E+00
	4.38E+02	4.39E+02	4.39E+02	4.38E+02	4.38E+02	3.84E-01
44 Magnum,	4.19E+02	4.17E+02	4.18E+02	4.19E+02	4.18E+02	7.48E-01
JHP	4.22E+02	4.19E+02	4.19E+02	4.22E+02	4.21E+02	1.46E+00
2 m	4.22E+02	4.19E+02	4.19E+02	4.22E+02	4.21E+02	1.42E+00
	4.20E+02	4.18E+02	4.18E+02	4.20E+02	4.19E+02	1.14E+00
	4.24E+02	4.21E+02	4.22E+02	4.24E+02	4.23E+02	1.30E+00
44 Magnum,	4.31E+02	4.27E+02	4.29E+02	4.29E+02	4.29E+02	1.56E+00
LSWCGC,	4.25E+02	4.22E+02	4.23E+02	4.24E+02	4.24E+02	1.14E+00
4 m	4.36E+02	4.33E+02	4.33E+02	4.36E+02	4.35E+02	1.51E+00
	4.33E+02	4.32E+02	4.31E+02	4.34E+02	4.33E+02	1.18E+00
	4.36E+02	4.34E+02	4.33E+02	4.36E+02	4.35E+02	1.20E+00
44 Magnum,	4.22E+02	4.22E+02	4.22E+02	4.22E+02	4.22E+02	3.56E-01
LSWCGC,	3.94E+02	3.95E+02	3.95E+02	3.94E+02	3.95E+02	3.11E-01
8 m	4.24E+02	4.22E+02	4.24E+02	4.22E+02	4.23E+02	1.43E+00
	4.27E+02	4.25E+02	4.25E+02	4.27E+02	4.26E+02	1.09E+00
	4.26E+02	4.27E+02	4.27E+02	4.27E+02	4.27E+02	5.15E-01

Note: The start light screen from chronograph A is given as "start A," the stop light screen from chronograph A is given as "stop A," etc. The distance between the first light screen and the muzzle (2 m, 4 m, 8 m) is indicated. JSP is jacketed soft point, JHP is jacketed hollow point, and LSWCGC is lead semi-wadcutter gas check. AltP indicates an alternate propellant (gunpowder) was used. Each bullet type was shot five times.

differences, $t_{start,A} - t_{start,B}$, in the start reference instants (where $t_{start,A}$ is provided by the pulse from the first light screen of Chronograph A, namely light screen 1, and $t_{start,B}$ is provided by the pulse from the first light screen of Chronograph B, namely light screen 2, where these pulses are shown in fig. 6), which are dependent on bullet type and, for the 44 Magnum bullet, exceed u_{t_d}. The Δt_d for the 44 Magnum bullets are greater than that for the 357 Magnum bullets and, for the 44 Magnum bullets, exceeds u_{t_d}. The cause of this difference between the 357 Magnum and 44 Magnum bullets has not yet been determined and was reduced by about 50 %, but not eliminated, when moving the chronograph so that the separation between the start lights screens and the muzzle was about 8 m. The likely cause of this difference ($t_{start,A} - t_{start,B}$) is an electronic issue (trigger recognition, pulse generation, or both) within one of the start light screens that may be differentially affected by the greater magnitude of the shock wave from the 44 Magnum compared with that from the 357 Magnum.

Although it is important to understand the impact of this new configuration on timing measurements, ultimately, it is the standard uncertainty in the estimated bullet velocity that is the important metric, as this is what determines whether a shot or a series of shots is acceptable for determining if armor meets or exceeds the requirements of the NIJ standard. The information on the series of bullets shot in the work is shown in Table 4. Data for different muzzle-to-first-light-screen separations are also shown in Table 4 for the 44 Magnum shots. The 44 Magnum shots show a greater standard deviation in bullet velocity than that for the 357 Magnum shots, except for the 44 Magnum shots at 8 m. The reason for this difference may be due to the flight characteristics of the bullet or another unrecognized phenomenon.

Conclusion

The new configuration of the light screen pairs described herein resulted in an average combined instrumental uncertainty for two chronographs for all shots of approximately 0.96 m/s, or about 0.69 m/s for one chronograph; both are less than the limit of 1.0 m/s specified in NIJ–0101.06.[1] Moreover, the uncertainty in the separation between light screens is easier to compute than it is for the staggered or nested light-screen configurations. Lastly, the new configuration allows the start and stop light screens of the two chronographs to have nominally the same separation (within the combined measurement uncertainty of that separation) and to have nominally the same center.

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