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Procedure for Surveying a Station in the U.S. Army Research Laboratory Transonic Experimental Facility Spark Shadowgraph Range

by John J. Heath

ARL-TN-614 **June 2014**

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14. ABSTRACT
The indoor instrumented spark range at the U.S. Army Research Laboratory Transonic Experimental Facility was designed for firing various-caliber projectiles to establish their free-flight characteristics. The in-flight position and orientation of the projectile is measured using 25 orthogonal pairs of spark photography stations, providing a set of shadowgraphs. An intrinsic part of the spark range instrumentation is the complex fiducial system that resides within the facility. This report presents the step-by-step method used to survey one of the 25 orthogonal fiducial stations using specialized equipment and techniques. Such a survey may be conducted to measure and record the position of an existing fiducial bead, reattach a bead to an existing fiducial wire, or be part of a larger effort to replace a broken or damaged fiducial wire or other system component.

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1. Introduction

The indoor instrumented spark range at the U.S. Army Research Laboratory (ARL) Transonic Experimental Facility (TEF) was designed for firing various-caliber projectiles to establish their free-flight characteristics.[1] The in-flight position and orientation of the projectile is measured using 25 orthogonal pairs of spark photography stations, providing a set of shadowgraphs. The angular and positional data obtained from the shadowgraphs is fitted to mathematical models of projectile motion that allow characterization of the aerodynamics and flight dynamics. (See Davis et al.[2] for a more detailed description of the history and methodology associated with the TEF spark range.)

An intrinsic part of the spark range instrumentation is the complex fiducial system that resides within the facility.[3] This report explains how to survey one of the 25 orthogonal fiducial stations using a SOKKIA SET4110 electronic total-station theodolite. Such a survey may be conducted to measure and record the position of an existing bead, reattach a bead to an existing fiducial wire, or be part of a larger effort to replace a broken or damaged fiducial wire.

Figure 1 shows an indoor view of the TEF spark range, looking uprange toward the gun, which is located outside the building. The projectile would be traveling toward the camera position from which this photograph originated. Prior to firing the gun, the indoor range lighting is turned off. Light sensors and preset time-delay units trigger high-voltage spark sources, causing the projectile shadow to be projected onto reflective screens mounted on the wall and ceiling. Photographs of the reflective screens, containing the projectile and shadow, are captured on 4- × 5-in photosensitive film.

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[1] Rogers, W. *The Transonic Free Flight Range;* BRL Report No. 849; U.S. Army Ballistic Research Laboratory: Aberdeen Proving Ground, MD, 1953.

[2] Davis, B.; Guidos, B.; Harkins, T. *Complementary Roles of Spark Range and Onboard Free-Flight Measurements for Projectile Development;* ARL-TR-4910; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, August 2009.

[3] Braun, W. *Fiducial Systems for the Free Flight Spark Ranges;* BRL MR 2009; U.S. Army Ballistic Research Laboratories; Aberdeen Proving Ground, MD, 1969.

Figure 1. View of TEF spark range, looking up-range toward gun position.

Figure 1 also shows the covers of the benchmarks, located on the spark range floor, used during the survey procedure. These benchmarks were emplaced onto pylons that were driven into the bedrock when the facility was constructed, with the specific purpose of providing a basis for accurate survey bead referencing.

Figure 2 is an example of a shadowgraph obtained from the TEF spark range showing a 155-mm projectile flying at supersonic velocity. The slightly blurred upper image is that of the projectile itself, and the crisp lower image is that of the projectile shadow projected onto a reflective screen. The shadowgraph also provides imagery of a variety of air flow structures around the projectile, such as shock waves and turbulent flow patterns.

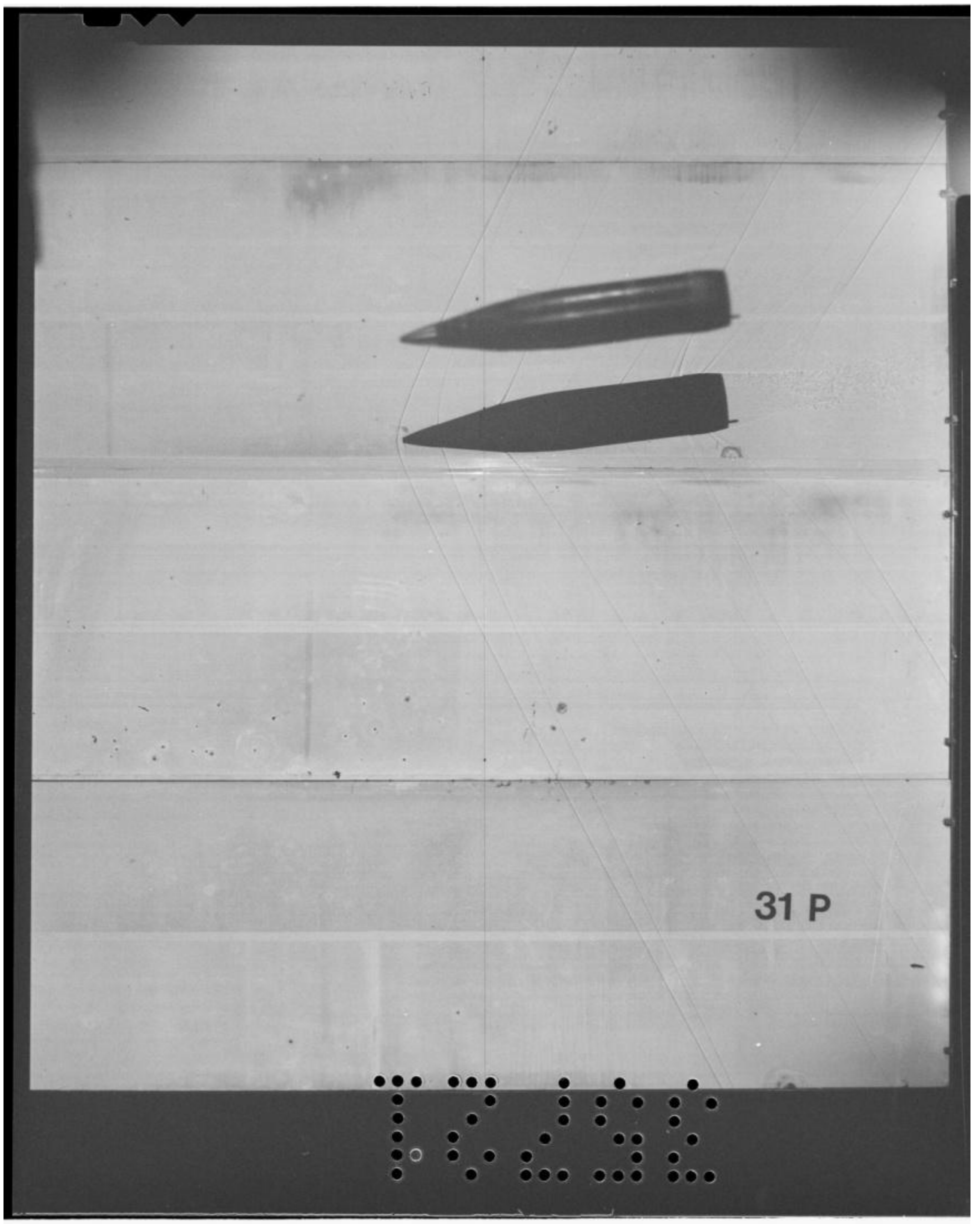


Figure 2. Shadowgraph, shot 35721, station 31P.

The position and orientation of the projectile itself is obtained from the shadowgraph by measuring the position and orientation of the projectile shadow relative to the shadow of the fiducial wire and beads. The fiducial beads are attached to the fiducial wire, visible in the previous figure as a vertical line in the shadowgraph. Figure 3 is a magnified view of the same shadowgraph, highlighting two fiducial beads (and their shadows) on the fiducial wire. The image of one of the fiducial beads is nearly covered by the projectile shadow. For this reason, multiple beads (primary, secondary, etc.) are attached to the fiducial wire so that one bead is always visible in the shadowgraph. Locations of the beads and fiducial wire dimensions are described in appendix A.

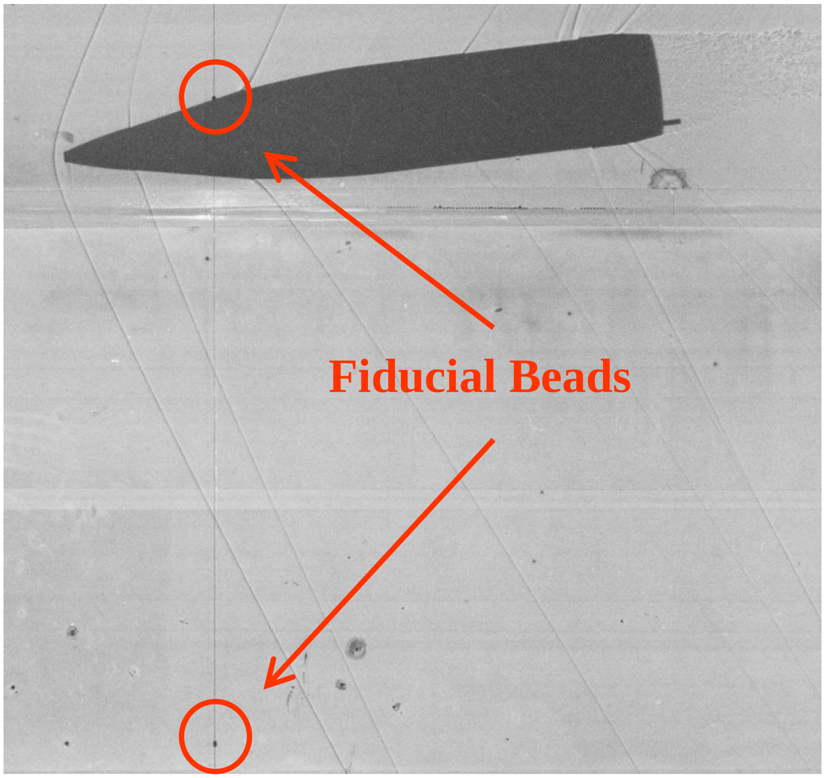


Figure 3. Magnified view of shadowgraph showing fiducial beads.

2. Survey Procedure

Table 1 lists reference elevations used in the survey procedure at each of the 25 spark stations. These elevations are for the survey control bead height on the wall side of the range. The spark stations are identified using an alphanumerical designation, as follows. The spark stations are orthogonally paired at 25 stations with five groups containing 5 stations each (for a total of 50 pieces of film per shot). The stations are identified with a two-digit number. The first digit indicates the group to which the station belongs (1–5), and the second digit indicates the station (1–5) within that particular group. Station 3-1 is the first station in the third group, i.e., the 11th of 25 stations.

Each individual shadowgraph is identified on the film using the same alphanumerical designation. The side view shadowgraphs, obtained from exposed film plates mounted on the left wall of the facility and reflective screens on the right wall, are designated with a “W.” The bottom view shadowgraphs, obtained from exposed film plates mounted in pits in the floor of the facility and reflective screens mounted on the ceiling, are designated with a “P.” Station 31P is the pit shadowgraph from the first station in the third pit.

Table 1. Reference elevations for spark stations.

Station No.	Elevation (in.)
1-1	0.885
1-2	0.885
1-3	0.885
1-4	0.885
1-5	0.885
2-1	0.750
2-2	0.752
2-3	0.754
2-4	0.756
2-5	0.759
3-1	0.710
3-2	0.714
3-3	0.718
3-4	0.722
3-5	0.726
4-1	1.072
4-2	1.077
4-3	1.082
4-4	1.090
4-5	1.096
5-1	1.079
5-2	1.086
5-3	1.093
5-4	1.100
5-5	1.108

The step-by-step survey procedure for one station is as follows:

1. Place the center of the heavy tripod stand over the benchmark of station (figure 4) to be surveyed and lock down the tripod (figure 5).
2. Level tripod.
3. Place theodolite onto tripod stand and lock it down (figure 6).

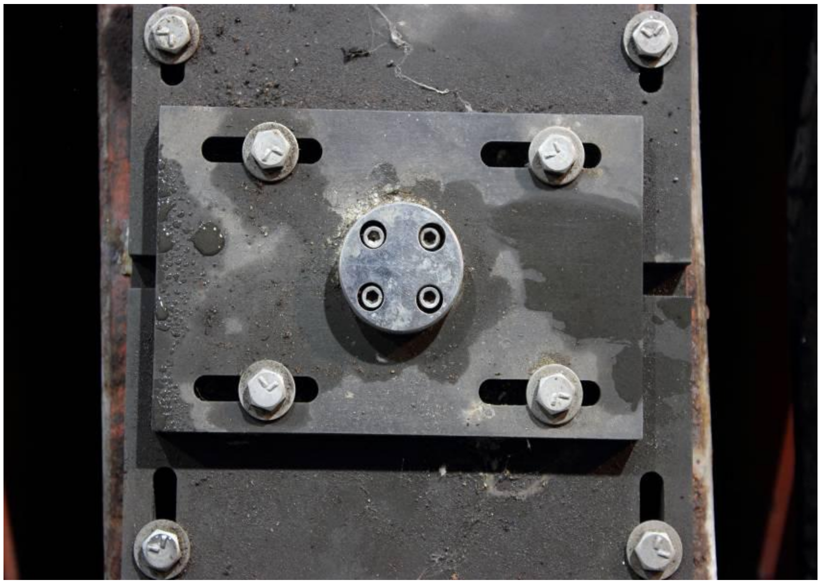


Figure 4. Benchmark of station being surveyed.

Figure 5. Heavy tripod positioned over benchmark.

Figure 6. Theodolite mounted on tripod.

4. Using a charged battery, turn on theodolite and rotate theodolite 360° and tilt head 180° to index the coordinate system. Manually level the theodolite using the three leveling screws. Press SFT+ (.) to display electronic level graphics, and then press the F1 key, which will indicate how close the instrument is to being electronically level.
5. Once leveled, look at the display screen and press the FNC key until P3 comes up on the screen.
6. Now press the F3 key and the menu screen will appear, then press (1.coordinate) with the enter key.
7. The coordinate screen will then be displayed; scroll down to STN DATA using the arrow keys and press the enter key.
8. Zero the N, E, and Z coordinates using the number key pad to the right of the display. After zeroing the N coordinate, press the enter key. Zero the two remaining coordinates in the same manner. Then press the F4 function key to take you back to the coordinate page.
9. Looking through the optical plummet of the theodolite, align the plummet centerline with the intersection of the survey bench mark (figure 7) using the micrometer adjustable plates (figure 8) on the tripod stand. Recheck the level of the instrument.

Figure 7. Theodolite optical plummet lined up with benchmark center marks.

Figure 8. Micrometer adjustable plates.

10. Go to “observation” on the coordinate page of the display using the arrow buttons, then press the enter key.
11. The coordinate page will display the vertical angle (ZA) and the horizontal angle (HAR).
12. Loosen the vertical movement lock and adjust the theodolite head with the fine-tune knob until the vertical angle reads 90.00.00.

13. Each one of the 25 orthogonal stations has a known elevation height, which are shown in Table 1.

14. Place level rod tripod over screen side benchmark, which is located at the third station of each pit.

15. Make sure lower section of the level rod is over the benchmark button (figures 9 and 10).

Figure 9. Elevation rod location.

Figure 10. Lower section of elevation rod positioned over benchmark.

16. Position the upper section of the level rod onto the lower section and level the tripod, making sure that the lower section of the rod stays over the benchmark (figure 11).

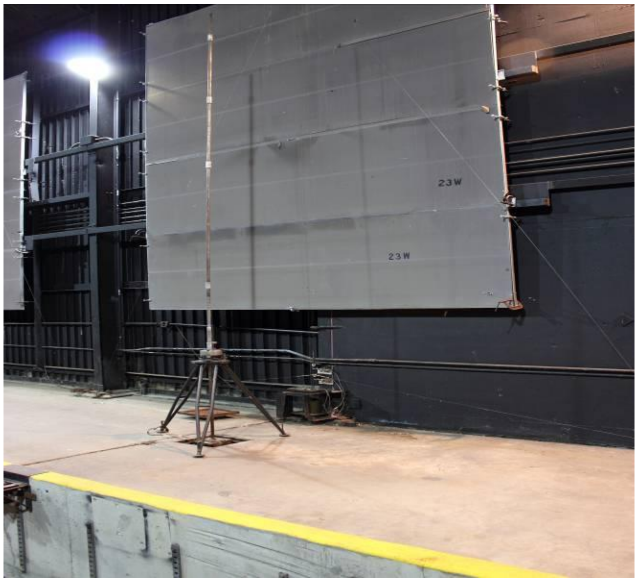


Figure 11. Upper section of elevation rod positioned on lower section.

17. Once the tripod is level, adjust the rod to the station height that is being surveyed by turning the micrometer adjustment barrel (figure 12).

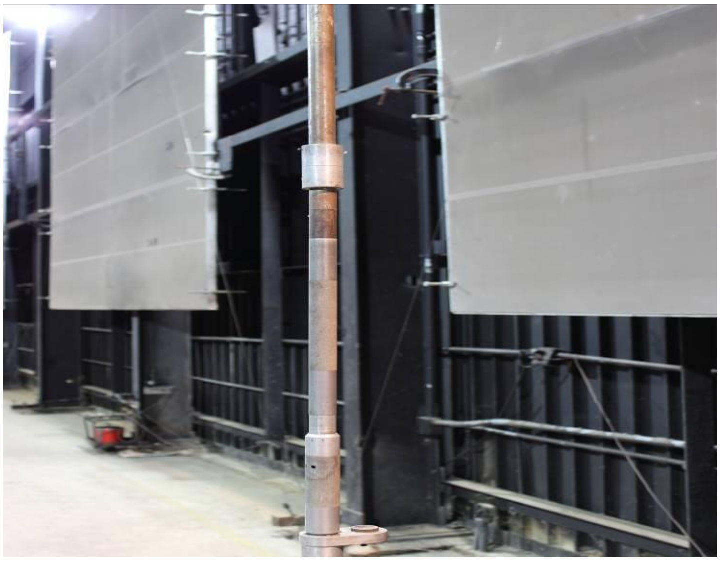


Figure 12. Micrometer barrel used to set the height of the elevation rod for each station.

18. With the vertical angle still at 90.00.00, adjust the vertical crosshairs in the theodolite to the elevation rod marks by raising or lowering the elevation mechanism on the theodolite tripod.

19. Once the theodolite is at the elevation height for that station being surveyed, the horizontal angle (HAR) can be set.

20. Press the (ESC) button on the theodolite and scroll down using the arrow keys to “set h angle.” Press enter (figure 13).

Figure 13. Theodolite being zeroed before turning a 90° horizontal angle, using a pointed survey cone specifically made to be positioned over any benchmark.

21. Align the theodolite head’s horizontal lines with the center of the survey cone that is positioned over another benchmark two stations away. Type in 180.00.00 using the key pad to the right of the display, then press the enter key.

22. The coordinate page will be displayed. Press the enter key while OBSERVATION is highlighted.

23. Reset the vertical angle (ZA) to 90.00.00, then loosen the horizontal locking knob and rotate the theodolite until the horizontal angle is 90.00.00 from the 180.00.00 that was set. Make sure both adjustment knobs are locked. To keep the angles set, use the fine-adjustment wheels.

24. Steps 25 thru 27 are used to survey the screen (wall) side of the range (figure 14).

Figure 14. Survey bead and wires for the screen (wall) side of the range.

25. Looking through the optics at the crosshairs in the theodolite head, the bead should be in the center of the horizontal line and the wire in the center of the vertical line. If not, the bead and wire need to be put back into survey.

26. Make sure the survey motor and plate have power connected to them. There will be a single light indicating power on the plate.

27. To move the bead up or down, adjust the downrange or uprange turnbuckles attached to the survey motor (figure 15). While bringing the bead back into survey, observe the movement of the wire. The centerline of the wire and bead must be aligned with the crosshairs in the theodolite head. If the bead cannot be brought back into survey using the turnbuckles near the motor, a one- or two-man lift must be used to adjust the turnbuckle at the top in the center of the screen. Once the bead and wire are in survey, there should only be the power light on the survey plate. If more lights are on, adjust the feeler gages or unlock the plate mounting screws and move the plate till only the power light is on. Retighten the plate mounting screws. Recheck the bead and wire position. Repeat the procedure if necessary. The gaps between the feeler gages should be approximately 0.050 in.

Figure 15. Survey motor with turnbuckle adjustments and feeler gage system used for the (wall) side of the range.

28. Steps 29–35 are used to check and survey the bead and wire on the pit screen (wall spark) side of the range.

29. To check the survey bead and wire location on the pit screen (wall spark side of the range), a 90.00.00 elbow scope eyepiece must be screwed onto the optics of the theodolite head (figure 16).

Figure 16. 90° elbow scope attached to theodolite head used to check the survey of the (pit) bead (spark side).

30. Once the eyepiece is attached, unlock the vertical lock to the head and adjust the head to another angle of 90° with the theodolite head looking straight up. Lock the vertical hold knob and adjust to desired angle with the fine tune knob. Make sure the horizontal angle remains the same; adjust if necessary.

31. Look through the eyepiece for bead and wire location (figure 17); if the bead and wire are not in the center of the crosshairs in the theodolite head, they will have to be adjusted.

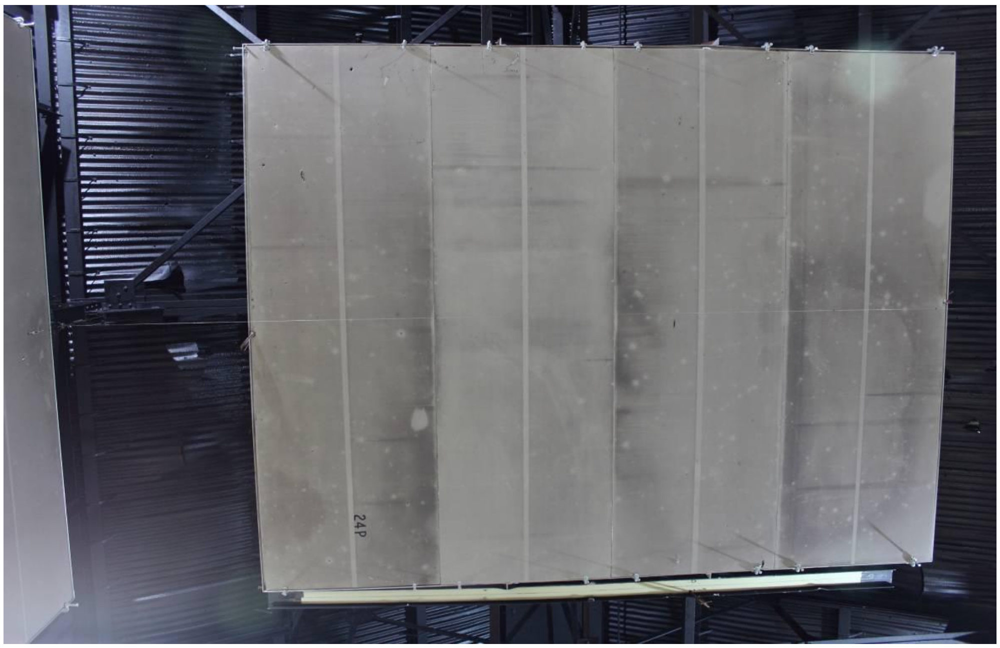


Figure 17. Survey bead and wires for the spark (pit) side of the range.

32. Make sure power is on the survey plate on spark side of the range.

33. Adjust the wire by using the uprange and downrange turnbuckles attached to the survey motor (figure 18).

Figure 18. Survey motor with turnbuckle adjustments and feeler gage system used for the spark (pit) side of the range.

34. To put bead into survey, there is a turnbuckle on the catwalk that needs to be adjusted. A ladder is needed to get to the turnbuckle (figure 19).

Figure 19. Spark side turnbuckle on catwalk that adjusts the pit survey bead.

35. With the bead and wire in survey, look at the survey plate to make sure only the power light is on. If any of the other lights on the plate are lit, you must move the feeler gages until the light goes out or move the mounting plate. Recheck the bead and wire location and repeat adjustment process as necessary. Again, the gap between the feeler gages should be no more than 0.050 in.

36. Now the orthogonal station is in survey. All other stations are surveyed using these steps.

3. Summary

The TEF indoor instrumented range was established in the early 1950s. Survey accuracy for each station using this system can be achieved to within .003–.005 in., corresponding to the location of the benchmark, to ensure precise measurements of the trajectory (yaw, pitch, and transverse displacements) for various types of projectiles fired through the instrumented range from which the aerodynamic characteristics can be determined. All angles turned for each survey station are (90°) horizontal and vertical angles with the benchmark as the reference point. All stations are surveyed in the same manner.

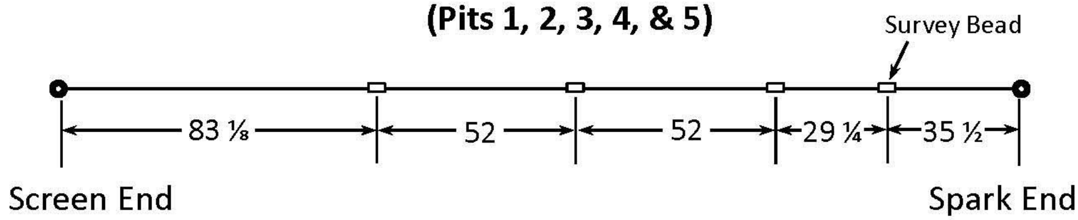
Appendix. Fiducial Wire Dimensions

Each fiducial wire has several fiducial beads attached to it, including the survey bead. The fiducial beads are used to establish the position and orientation of the projectile when analyzing the spark shadowgraph data. The fiducial beads are emplaced on the wire relative to the survey bead according to the following diagram.

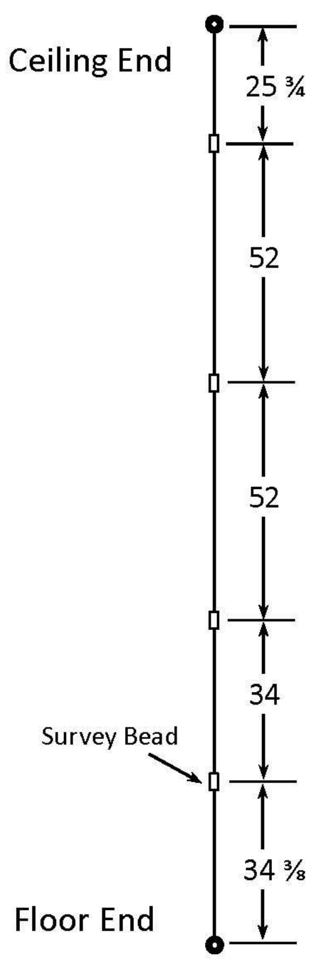
Fiducial Wire Dimensions

(all dimensions in inches)

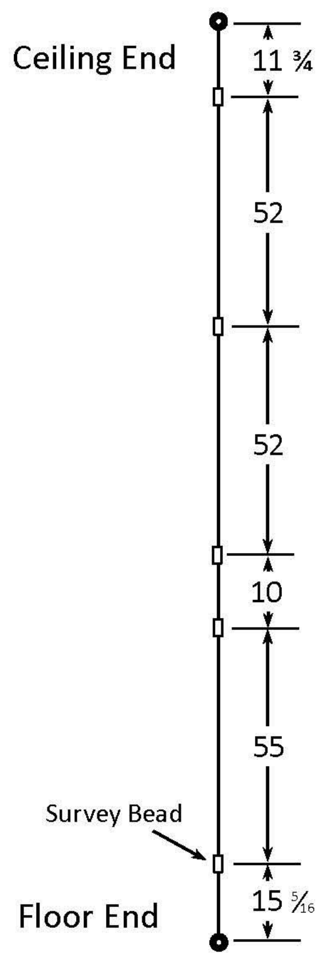
Pit View Wires
(Pits 1, 2, 3, 4, & 5)



Wall View Wires
(Pits 1 & 2)



Wall View Wires
(Pits 3, 4, & 5)



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