

Sniper Target Tracking Analysis of John F. Kennedy Assassination

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ABSTRACT

US President John F. Kennedy was assassinated by a sniper while riding in an open limousine in Dallas, Texas on 22 November 1963. Although official investigations established that three shots were fired from a sniper's nest in the Texas School Book Depository, a complete reconstruction of the sequence of shots was not thoroughly established. Subsequent research has led to a consensus that the first shot missed, but a complete explanation has eluded investigators. This paper presents a quantitative analysis of the sniper targeting effort, including the advantages of the sniper's nest and eventual marksmanship difficulty. It is quantitatively shown that the three-dimensional target tracking was significantly reduced as the motorcade proceeded away from the sniper's nest. The reduction in apparent motion of the target correlates with the increasing accuracy of the three shots, suggesting this variable plausibly factored into the enigmatic hit-and-miss pattern.

Keywords: assassination, exterior ballistics, President John F. Kennedy, Warren Commission, shooting reconstruction, crime scene reconstruction, forensic science

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Introduction

US President John F. Kennedy was assassinated while riding in an open limousine within a motorcade through the city of Dallas, Texas on Friday, 22 November 1963. President Kennedy had appeared in numerous such motorcades routinely during his presidency as well as during the 1960 presidential campaign. The Dallas motorcade had proceeded without incident up until the end of the route when the President was suddenly shot twice by a sniper at 12:30 local time in Dealey Plaza. The primary (and eventually, only) suspect in the crime was Lee Oswald, an employee of the Texas School Book Depository (TSBD), which had a warehouse

overlooking the motorcade route. Oswald, who had only worked there for a couple of weeks, went missing after the assassination and was apprehended in connection with the murder of Dallas police officer J. D. Tippit (in the neighborhood where he happened to live) that same afternoon. Oswald himself would be murdered two days later while being transferred to the Dallas County Jail by a local vigilante named Jack Ruby. With the death of the only suspect in the crime, President Lyndon B. Johnson (Kennedy's successor) would go on to establish a bipartisan Presidential Commission by Executive Order. Johnson



appointed Supreme Court Chief Justice Earl Warren to lead it, thus it became informally known as the “Warren Commission” or “WC” for short. Based on its investigation, the WC would determine in 1964 from the available evidence that Lee Harvey Oswald was the lone assassin, firing three shots at the President from a “sniper’s nest” window located in the southeast (SE) corner of the 6th floor of the TSBD building overlooking Houston and Elm Streets. The Commission considered the question of a conspiracy, but ultimately found no compelling evidence of one [1, p. 374]. The murder weapon found at the crime scene (and ballistically matched to recovered bullet fragments) was an Italian military *Carcano Fucile di Fanteria* (infantry rifle), *Modello 91/38* (Model 1891/1938), manufactured in 1940 at the Royal Arms Factory in Terni, Italy¹ and owned by Lee Oswald.

Before the Commission’s establishment, concurrent with its investigation, and subsequent to the publication of the Report, vocal skeptics proliferated and espoused “conspiracy theories.” Some, but not all, of these arose out of genuine inquiry concerning various findings in the Commission’s report [2–4]. In response to these skeptics, additional independent US federal government investigations would be commissioned [3, 4], along with other non-government investigations [e.g., 5–13], each of which ultimately affirmed the WC’s basic findings given the overwhelming physical and circumstantial evidence.² Although the House Select Committee on Assassinations (HSCA) reached the conclusion that President Kennedy “was probably assassinated as a result of a conspiracy” [14, p. 1] based on disputed “acoustics evidence” [4, 15–17], they nevertheless corroborated from the remaining evidence that the two shots that actually hit and killed President Kennedy (along with a missed shot) were fired from the sniper’s nest.

One of the early difficulties in the WC Report that would lead to criticism was an odd hit-and-miss pattern to the three shots. It

was determined through physical evidence and eyewitness testimony that 3 shots had been fired at the motorcade, but the physical evidence from only 2 of these bullets were recovered from the crime scene. This implies that one of the shots completely missed the limousine (and was never found as a result). The Commission was agnostic about which shot missed [1, p. 117], but under the general assumption that the third shot struck President Kennedy in the head, it nevertheless subtly disfavored the scenario of the first shot missing [1, p. 111] since it appeared to be implausible that the first shot, by far the closest of the three, would have missed [3, p. 468]. This implicit assumption would lead to a widely held view that the assassin had only approximately 6 seconds to fire the three shots [18], requiring two recycles of the bolt-action Carcano rifle. Although this would not have been impossible for Oswald, who had served in the United States Marine Corps (USMC) and qualified as “Sharpshooter” with the M1 Garand rifle on targets more than twice the range in Dallas, it nevertheless was not trivial either, given the target was moving obliquely to the line-of-sight and target reacquisition would be required after each cycle of the bolt. However, subsequent research, some of it based upon the earlier frames of the 8 mm home movie by Abraham Zapruder (i.e., the “Zapruder Film”), coupled with eyewitness testimony (including Governor Connally’s), has led to a consensus that it was in fact the first shot that missed [2, 3, 10, 15, 16, 19, 20]. This finding was an important development following the publication of the WC Report, because it increased the assassination time span from approximately 6 seconds to in excess of 8 seconds, which significantly reduced the presumed difficulty of the shots [2, 3, 18].

However, the increased assassination timeframe (8+ s) reintroduced the earlier conundrum considered by the WC, namely the proposition that the same sniper who would bull’s eye Kennedy in the head a moment later, would not only miss Kennedy while he was just below the TSBD window, but all the other occupants in the limousine as well, indeed the entire limousine. As a result of this, various researchers have proposed a number of different reasons to explain why the first shot missed. Some, including the WC [1, p. 111] and others [e.g., 19, p. 146], have suggested the first shot

1. www.MilitaryFactory.com, Carcano Modello 1891 (M91) Bolt-Action Service Rifle/Carbine (1892); https://www.militaryfactory.com/smallarms/detail.asp?smallarms_id=443

2. In fact, more than 50 separate pieces of evidence implicate Lee Oswald [3, pp. 952–969].



may have been deflected by the southern live oak tree that obstructed a portion of the street [2]. More recently it has been argued that it may have been deflected far downrange (thus wounding a bystander-witness who was located near the triple underpass) by an overhanging traffic light assembly [20], or that the shot simply missed the limo entirely without being deflected by an obstacle, then disintegrating upon direct collision with the asphalt [10, 15]. This article is not intended to favor explicitly any of these three mutually exclusive scenarios, but rather seeks to quantify an additional variable that ultimately factors into all of them, namely the targeting difficulties confronted by the would-be assassin in Dealey Plaza.

Analysis

Careful examination of the logistics of the Kennedy assassination (detailed below) suggests that the “sniper’s nest” provided an optimal vantage point and targeting range for carrying out the assassination in Dealey Plaza (Fig. 1). The following subsection briefly examines the advantages implicitly afforded by this location, and this is followed by a quantitative analysis of the actual shots as they would play out.

Sniper Targeting Logistics

There were a number of reasons the assassin’s chosen location and targeting were superior to other viable locations in Dealey Plaza, the most obvious being the necessity of cover and unobstructed views of the target, along with unmitigated access to the upper floors of the TSBD. What follows is a more detailed consideration and quantitative analysis of the exact location and range (viz., shots down Elm Street from the TSBD 6th floor SE window).

Sniper Positions. One may readily see in Fig. 1 that there were a finite number of viable sniper locations in Dealey Plaza. Most locations, including the railroad triple overpass (not visible in the figure), would have been prohibitive in a real-world scenario given they would have been out in the open without cover and thus fully exposed to adjacent onlookers (many presumably with cameras) and law enforcement. That said, in addition to the TSBD 6th floor SE “sniper’s nest” window (including its multiple targeting ranges up Houston and down Elm Streets), three hypothetically viable sniper locations have been selected for comparison

purposes: The 6th floor southwest (SW) window, the Dal-Tex Building, and the “Grassy Knoll.” The SW window is a location some eyewitnesses reported seeing a man with a rifle [3, 16] and some conspiracy authors have claimed is visible in a photo taken by a Dallas Morning News photographer [e.g., 21, pp. 208]. Note that the SW window presents a counter option available to a TSBD shooter (including Oswald), one that at first glance might seem better suited for shots down Elm Street given its closer proximity. The Grassy Knoll, of course, is the place most conspiracy proponents, including the HSCA, place a second gunman [e.g., 16, 22–26]. Although no physical evidence was ever recovered from this location and it has otherwise generally been discredited for multiple reasons [3, 4, 9, 11, 12, 15, 17, 19, 27]. Some have conjectured that the Dal-Tex building, located on the far right side of the figure, may have had a sniper [e.g., 21, pp. 21, 184–185], [25, p. 55], so it has also been included for comparison. While there may have been a viable shot from one or more of those windows and the forensic evidence does not necessarily rule out the fatal shot being fired from a building to the rear at this location with a similar weapon [e.g., 1, 12, 15, 28], such a location and any of the other buildings to the rear would have posed serious logistical challenges. These would include physical obstructions, including trees, signs, light fixtures, onlookers, other cars in the motorcade, especially the Secret Service follow-up car, and the non-trivial hurdles associated with gaining access and proper cover from within a building. But it should be borne in mind that there was and is no physical evidence that any shots were fired from the Dal-Tex or other such buildings, so, like the Grassy Knoll, such locations are purely hypothetical.

Geometry. The amount of tracking for a moving target can be expressed as a tracking angle in degrees. Using the 12 hour clock as a reference, a tracking angle of 30° is the equivalent of swinging one’s aim from their 12 to 1 o’clock. Determination of the relative amounts of tracking (i.e., pivoting the rifle sights with a moving target) required of various sniper options at Dealey Plaza is a matter of simple Euclidean geometry, given an accurate three-dimensional (3-D) model of Dealey Plaza. To this end, the author utilized Google Earth Pro, which provides accurate 3-D models for cities



across the world, including Dallas, Dealey Plaza and the former TSBD³ (see Fig. 1).

Google Earth facilitates the accurate tracing and measurement of paths and trajectories in the 3-D space of Dealey Plaza. Line segments of lengths Δx are first traced along Houston and Elm Streets to represent the movements of the Presidential Limousine within the motorcade. The length of these line segments have been set to be approximately equal to the distances between the three known shots (the missed shot, the shot that hit both President Kennedy and Governor Connally, and the fatal shot), these being $\Delta x \approx 30.0$ m (98.4 ft) and 20.4 m (66.9 ft). These limo paths are represented with red lines in Fig. 1. Note that the Elm Street line segment just below the TSBD SE window begins at where the limo would have made the turn and terminates at the tree obstruction, thus limiting the tracking swath to about $\frac{2}{3}$ the length of the other two. Connecting the end points of these line segments with various viable sniper locations form lines-of-sight, s_1 and s_2 , that sweep out the scanning range for any would-be sniper taking those shots (pink, orange, magenta, blue, cyan, and green lines in Fig. 1). These lines-of-sight, combined with the limo paths, form triangles constituting “targeting swaths” that encapsulate the sniper tracking in the 3-D space of Dealey Plaza, with the potential amount of tracking (pivoting of the weapon) quantified in the form of angular distances. It should be noted that the target tracking swaths must precede the space where shots are to be attempted—thus, the tracking swaths begin prior to shot locations.

The physical lengths of the each of these trajectories or lines-of-sight in the model Dealey Plaza comprise two sides of a triangle, which when taken with the limo path segments Δx , constitute three known sides. One may thus calculate any angle A of each triangle from the law of cosines

$$a^2 = b^2 + c^2 - 2bc \cos(A) \quad (1)$$

3. The TSBD was renamed the Dallas County Administration Building in 1981 [29, pp. 74–75]. Note that the author verified the Google Earth Pro model height of the 6th floor to be approximately equal to 18 m (59 ft), which agrees with the reported height of 60 ft. The author also spoke with Google Earth developers at the 2017 American Geophysical Union Meeting in New Orleans who verified that the 3-D building models are of research quality and accuracy.

where a , b , and c are the known sides, a being the side opposite of angle A . Making the following substitutions, $a \equiv \Delta x$, $b \equiv s_1$, $c \equiv s_2$, and $A \equiv \Delta\theta$, within Eq. (1), and solving for the unknown sniper tracking angle $\Delta\theta$ leaves

$$\Delta\theta = \arccos\left(\frac{s_1^2 + s_2^2 - \Delta x^2}{2s_2s_1}\right) \quad (2)$$

As mentioned above, the limo paths Δx (the red lines in Fig. 1) are approximately 30.0 and 20.4 m. The corresponding linear measurements of each of the lines-of-sight s_1 and s_2 (the pink, orange, magenta, blue, cyan and green lines in Fig. 1) from Google Earth Pro are given in Table 1. Plugging these values for s_1 and s_2 into Eq. (2) yields the values for angle $\Delta\theta$ as given in the last column of Table 1.

Calculations and Discussion. These calculated values of $\Delta\theta$ provide a quantitative indication of the relative amounts of tracking that a sniper planning an assassination in Dealey Plaza would have been potentially faced with. Here it can be seen that the least amount of potential tracking was for targeting down Elm Street from the SE window of the TSBD (after the tree), where the sniper would only need to pivot the rifle by 7.5° from the first hit (after the limo cleared the tree) to the fatal shot (most of this being in the vertical dimension). To give an idea of how small this angle is, the minute hand on a 12-hour clock “pivots” 6° for each minute. This means that if the first shot after the tree is taken to be at the sniper’s 12 o’clock, then the fatal shot would have been just after the 12:01 mark. By contrast, targeting down Houston Street would have required approximately 20° of pivoting (not to mention the far greater risk of being spotted while taking a frontal shot), approximately 3 times as much, as would targeting down Elm Street from the SW window. And the Grassy Knoll? Tracking from there would have required pivoting the rifle approximately 34° , about 4.5 times as much as from the “sniper’s nest.” This would have been significantly more challenging in terms of a moving target. Obviously the assassin would not have gone through explicit geometrical calculations as has been done here, but whether intentional or not, it is arguably the case that taking shots down Elm Street from an upper floor of the SE corner of the

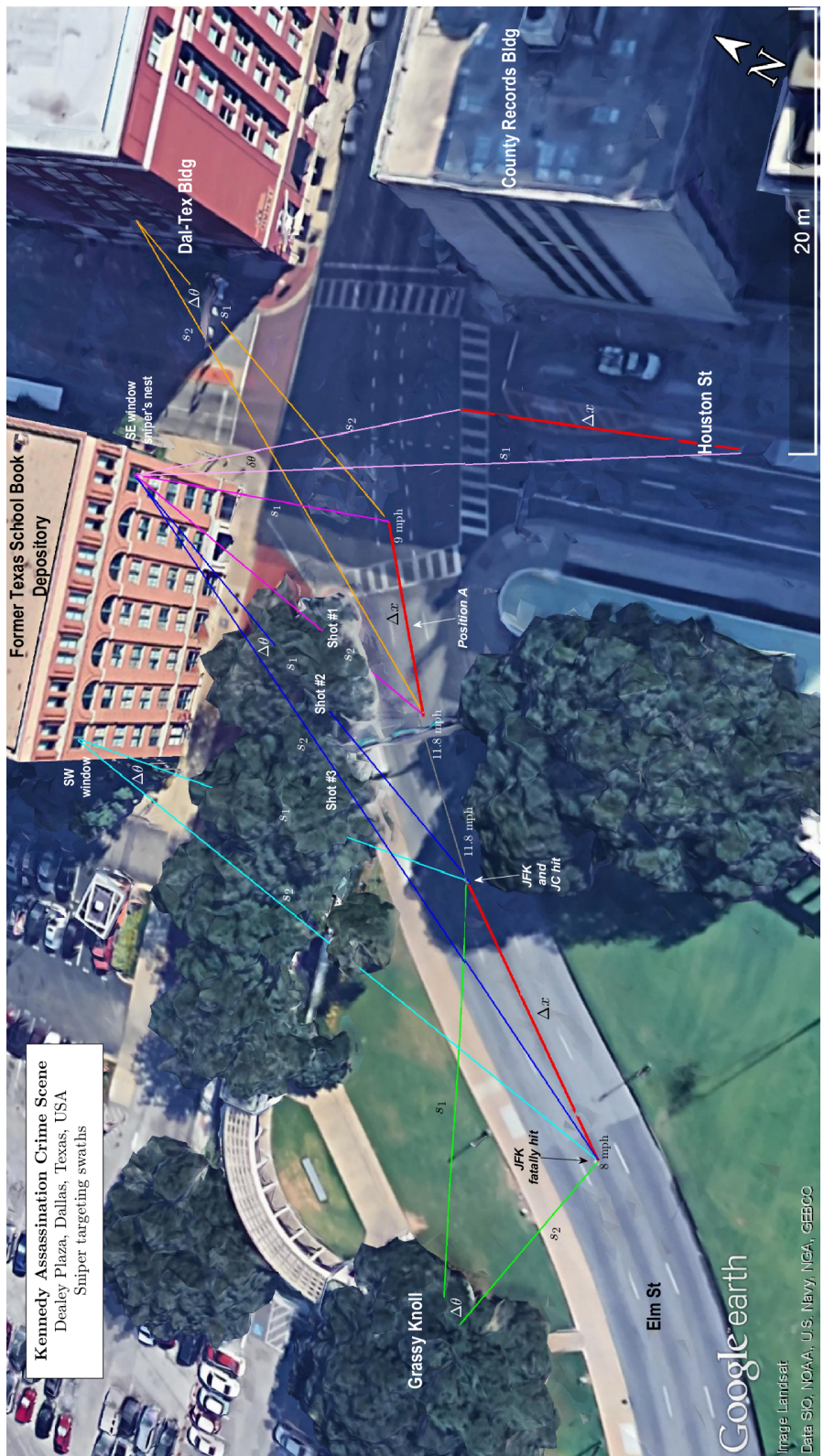


FIGURE 1: Targeting swaths for various ranges at the presidential motorcade in Dealey Plaza. The red line segments represent ranges of the motorcade route, each measuring Δx in linear distance along the ground (the gray line segment designates the approximate oak tree shadow zone). The end points of these segments are connected with viable sniper locations in the Plaza to yield targeting swaths for shots attempted in those locations. The pink lines-of-sight are for hypothetical targeting down Houston Street from the TSBD southeast (SE) window (the "sniper's nest"). The magenta and blue lines are for shots taken from the SE window down Elm Street, the former encompassing the area of the street prior to the oak tree (where the first shot missed around "Position A") and the latter defining the trajectories of second and third shots that hit the President. Finally, the cyan and green lines are for alternative targeting on Elm from the TSBD SW window and Grassy Knoll, respectively. Non-permanent geographic features (e.g., tree canopies, parking lot, road signs, cars, etc.) are contemporary with the year 2017 and not as they were in 1963, and the solar shadows are not valid for the historical date and time. Google Earth © Pro map data: Google, SIO, NOAA, US Navy, NSA, and GEBCO.



TABLE 1: Dealey Plaza sniper targeting trajectories and tracking swaths.

Sniper Location	Targeting Range	Δx	s_1	s_2	$\Delta\theta$
TSBD 6 th floor SE	Houston St	30.0 m	58.3 m	32.2 m	19.7°
TSBD 6 th floor SE	Top Elm St (before tree)	20.4 m	25.4 m	36.0 m	33.5°
TSBD 6 th floor SE	Mid Elm St (after tree)	30.0 m	51.0 m	79.8 m	7.5°
TSBD 6 th floor SW	Mid Elm St (after tree)	30.0 m	40.9 m	64.9 m	20.1°
Dal-Tex 2 nd floor	Top Elm St (before tree)	20.4 m	43.7 m	61.7 m	10.6°
Grassy Knoll	Mid Elm St (after tree)	30.0 m	49.9 m	29.7 m	33.5°

TSBD constituted an optimal sniper location and targeting range in Dealey Plaza in terms of minimizing tracking on a moving target.

Difficulty of Shots

Although the calculations of $\Delta\theta$ demonstrate that targeting down Elm Street from the 6th floor SE window would potentially minimize tracking for a moving target, the eventual difficulty of the shots fired on 22 November 1963 would also depend upon the actual speed of the limousine. The slower the speed, the easier the targeting, regardless of location.

Geometry. Therefore, to assess the relative targeting difficulties of the eventual motorcade as it moved along Houston and Elm Streets, the limo speed at a given location x is approximated as an average over the travel distance, Δx , which is expressed in terms of the approximate finite difference equation

$$v \approx \frac{\Delta x}{\Delta t} \quad (3)$$

where Δt is the change in time in seconds and v is the average speed (m/s) of the limo over the path Δx . Likewise, the angular speed of a sniper tracking the limo is approximated as

$$\omega \approx \frac{\Delta\theta}{\Delta t} \quad (4)$$

where ω is the average angular tracking speed (deg/s) required for aiming at the target moving at speed v . Solving Eq. (3) for Δt yields

$$\Delta t = \frac{\Delta x}{v} \quad (5)$$

which may then plugged into Eq. (4) to yield an

expression for estimating the angular tracking speed

$$\omega = v \frac{\Delta\theta}{\Delta x} \quad (6)$$

From Eq. (6), the relative difficulty of the shots (in terms of a moving target) as they would have occurred can now be estimated given the actual speeds the limousine was traveling at on Houston and Elm Streets on 22 November 1963.

Limousine Speed. Although the limousine's speed was variously estimated to be in the neighborhood of 12–15 mph in areas where crowds had gathered [Testimonies of William Robert Greer and Clinton J. Hill, Special Agents, Secret Service, 30, pp. 115, 137] and the WC calculated from the Zapruder Film a somewhat smaller average speed of 11.2 mph down Elm Street prior to the fatal shot [1, p. 49], variations of the limo's speed are germane to the current analysis and thus examined in more detail. Both the limo driver (William Greer) and Clint Hill (the only Secret Service Agent who ran to the President's aid) testified that the limo "slowed" around the corners of Main and Houston, and then Houston and Elm, but only Hill provided reasonable estimates of the limo slowing down "to maybe 10 miles per hour" at Main and Houston [Ibid. 30, p. 137], and "maybe to 10, maybe to 9 [mph]" at the intersection of Houston and Elm [Ibid. 30, p. 138]. At the time of the first and second shots (that hit JFK), Clint Hill estimated "12 to 15 mph, but no faster than 15 mph" [Ibid. 30, p. 139]. It is unlikely that limo driver Agent Greer was accurate in his recollection of the car's



speed just before the fatal shot rang out, which he claimed it was “between 12 and 15 mph” [Testimony of William Robert Greer, Special Agent, Secret Service, 30, p. 119]. These limo speed estimates from the Secret Service agents’ testimonies are only estimates based upon their recollections but they provide a baseline from the most qualified witnesses.

Physicist Luis W. Alvarez carefully analyzed the photographic record contained in the Zapruder Film and arrived at more precise quantitative estimates for variations in the limo speed during Zapruder’s filming sequence. Alvarez calculated the limo’s speed to be steady at 11.8 mph before a sudden deceleration beginning at Zapruder Frame 300 (Z300) to approximately 8.0 mph [5]. Alvarez gives Greer the benefit of the doubt and only suggests that he took his foot off the accelerator, suggesting the car was being operated in a “low-gear ratio” so that taking the foot off the accelerator could cause a sudden deceleration. But eyewitness testimony suggests that the driver did in fact tap the brakes. The home movie taken by Orville Nix (i.e., the “Nix Film”) shows a sudden deceleration of the limousine that appears to dip below the 8 mph estimated by Alvarez, and this is confirmed in measurements reported in Itek Corporation’s 1967 Nix Film analysis [30], as well as in Appendix C of Josiah Thompson’s book (credited to William Hoffman), where in the latter the speed is seen to be steady at 8 mph over the course of Z304–Z313, but then suddenly dips to ≈ 6.5 mph by Z319 [23, p. 277]. Greer testified that the presidential limousine was an automatic transmission vehicle with three gears (one low gear and two “drive” gears) [Testimony of William Robert Greer, Special Agent, Secret Service 30, p. 121]. He also claimed the vehicle was in “low-gear,” [Testimony of William Robert Greer, Special Agent, Secret Service, 30, p. 120] but this seems implausible. As anybody who has driven a car knows, be it automatic or manual transmission, low-gear (or first gear) makes for a jerky ride, especially at speeds of “10–15 mph.” Automatic transmission vehicles are usually driven in “drive” (“D” on the shifter), thus allowing the automatic transmission to function as intended and provide a smooth ride at all speeds. Usually “low gear” is employed in situations where additional control is needed without riding the brakes—for example on roads with steep

grades, or during wintery/icy conditions. Given that Greer’s testimony conflicts with the fact that the limo did abruptly slow down, one may be less inclined to believe his testimony that the car was in low-gear, implying that he may in fact have tapped the brakes. Presuming this were true, there need not have been any sinister motivation at play, contrary to what conspiracy-minded authors might infer. Anti-conspiracy author Gerald Posner described it thus: “Incredibly, Greer, sensing something was wrong in the back of the car, slowed the vehicle to almost a standstill and turned in his seat to see what happened” [2, p. 233]. As seen in the Zapruder Film, Greer, momentarily disoriented as to what was happening (over a period of mere seconds), looked backward (and into his rear view mirrors), and realizing the President needed help, may have reflexively braked, perhaps to allow other Secret Service Agents from the follow-up car to assist (as Special Agent Clint Hill was in the process of doing). However, regardless of whether Greer tapped the brakes or simply lifted his foot off the accelerator, it should be noted that although the limousine did briefly slow down, it was only no more than a couple of mph.

From these estimates of the limousine’s speed on Elm Street, the target speed v just prior to each of the three shots can be estimated as follows. The first shot occurred shortly after the limo made the turn from Houston onto Elm (somewhere between “Position A”⁴ and the oak tree shadow zone), at which point it accelerated from 9 mph (as estimated by Clint Hill) to 11.8 mph (as calculated by Alvarez), thus the limo speed at the time of the first shot is estimated to be somewhere between these two speeds—for simplicity one may take it to be the mean, that is $(9+11.8)/2=10.4$ mph (4.6 m/s). The second shot occurred during the time frame where Alvarez estimated the limo’s speed to be a constant 11.8 mph (5.3 m/s). For the third and final shot, as estimated by both Alvarez and Thompson/Hoffman, the limo slowed from 11.8 mph to 8 mph just before JFK was fatally wounded. Again for simplicity it is taken to be the mean,

4. When the US Federal Bureau of Investigation (FBI) restaged the assassination in 1964 under the aegis of the Warren Commission, Position A was defined as the first point where a shot could have hit the President at the known point of entry on his upper back [32, pp. 144–146]. Note also that the upper torso (i.e., “center-mass”) is a target silhouette “kill zone.”



thus $(11.8+8)/2=9.9$ mph (4.4 m/s); note that this last estimate may be conservative given that the limo had already slowed to 8 mph by Z304 before dipping below this speed from Z313 to Z319 [23, p. 277].

Calculations and Discussion. From the values of v (listed in Table 2), one may calculate the angular tracking speed ω for each of the shots using Eq. (6), given $\Delta\theta$ and Δx . For shots 1 and 3 these values have been calculated and are given in Table 1 using Google Earth and Eq. (2). However, for the second shot the limousine path Δx between the two red limo paths marked in Fig. 1 (i.e., the light gray line) still must be estimated—this is essentially the tree shadow zone where the limousine was obstructed from sight by the tree. Using Google Earth, the approximate length of the tree shadow zone is found to be ≈ 17.6 m, which then allows calculation of the corresponding $\Delta\theta$ to be 12.3° using Eq. (2). It should be noted that exact knowledge the distances Δx of either the tree shadow zone (gray line) or any of the limo paths (red lines) is not necessary as these are simply used with the limousine speed estimates for approximating the tracking speeds required prior to any of the presumed shots.

Finally, given the values of Δx , s , $\Delta\theta$ and v (listed in Table 2), one may finally use Eq. (6) to calculate the angular tracking speeds ω for the three shots fired in Dealey Plaza from the TSBD SE window; these values are listed in the final column of Table 2. From these calculations a pattern emerges: The amount of apparent motion of the target from the vantage point of the TSBD SE window decreased as the limousine moved down Elm Street toward the triple underpass. Thus, when evaluating the difficulty of the shots in terms of the moving target (as is often pointed out by WC skeptics and conspiracy proponents when trying to denigrate Lee Oswald's marksmanship ability),

it is found that shots became progressively *easier* as the car approached mid-Elm Street. This may run counter to an ordinary lay person's intuition, whereby the closer shots would automatically be considered the "easiest." Indeed, even the WC had implicitly assumed that the first shot would have been the easiest, and thus it seemed implausible that it would have been the first shot that missed, which later led to the implicit favoring of the scenario whereby the second shot missed. Although previous authors have pointed out advantages of the TSBD SE window [e.g., 9], and that the third shot may not have been the hardest [e.g., 3, 15], the present work has conducted an explicit calculation (in 3-D space) of angular tracking speeds to support quantitatively these contentions. It should also be noted that the calculations based on Fig. 1 include *both* the horizontal *and* vertical components of tracking necessary for these three shots, not simply one or the other.

Discussion and Conclusions

From the above analyses and results (summarized in Tables 1 and 2) one may now make more sense of two questions surrounding the assassination, keeping in mind that "nothing just happens" in the cotext of crime scene reconstruction [33]:

1. Was it sensible for an individual committed to assassinating the President in a motorcade (a moving target) to take shots down Elm Street from the TSBD 6th floor SE window, as opposed to other sniper locations (e.g., the SW window, Grassy Knoll, etc.) and/or ranges (e.g., Houston Street), in Dealey Plaza?
2. Is there a plausible explanation for the seemingly converse hit-and-miss pattern (complete miss, hit center-mass, hit head)?

TABLE 2: Relative Tracking Difficulty for Shots Fired at the Presidential Limousine on Elm St from TSBD SE Window

#	Target Location	Outcome	Δx	s	θ	v	ω
1	Before tree, just below SE window	Complete miss	20.4 m	36.0 m	33.5°	4.6 m/s	7.6 deg/s
2	Just after limo cleared tree	Hit: upper torso, wounded	17.6 m	51.0 m	12.3°	5.3 m/s	3.7 deg/s
3	Mid Elm St	Hit: head, killed	30.0 m	79.8 m	7.5°	4.4 m/s	1.1 deg/s



With regards to the first question, in addition to the benefits of unimpeded access to the building and near-perfect cover in the 6th floor corner window, the selected sniper and targeting location appears to have been an optimal choice solely from the consideration of minimizing target motion. One should note here that the assassin would not have had exact foreknowledge of the motorcade's speed through the Plaza, and indeed, the limousine did move at variable speeds throughout Dallas. The positioning of boxes within the sniper's nest window as a makeshift gun rest is suggestive that the sniper intended to take deliberate, stabilized shots at mid-Elm Street after the limo cleared the live oak tree obstruction—precisely the location where target motion would be minimized—and this, in turn, is suggestive of premeditation.

Furthermore, it now also becomes more plausible that the first shot, possibly impulsive and unplanned (considering the gun rest), could feasibly be a complete miss, this in part because it was the most *difficult* of the three. This is true whether or not it was deflected by an obstruction, keeping in mind that the conscious avoidance of obstructions is implicitly more difficult for a faster moving target. Although it is not clear whether the assassin planned this shot or not, the shot was nevertheless rushed given the limited window of opportunity between Position A and the oak tree obstruction. The home movie by Robert Hughes (the “Hughes Film”) of the motorcade turning onto Elm Street did not show a rifle or person protruding from the TSBD SE window, but did show motion behind the window [34], and eyewitnesses variously testified that the first shot sounded “muffled,” or like a “firecracker” or “motorcycle backfire,” as if it were fired from inside the building [35, p. 495]. The pivoting needed to track the target below the window was approximately 8 degrees per second—this is faster by a third than the movement of the second hand on a 12 hour clock. While at first this may strike the reader as being somewhat “slow,” it in fact constitutes a significant moving target, especially when using a telescopic sight behind a window. Additionally, the tracking angle in 3-D space would have involved a combination of both vertical and horizontal movement, which is a more complex anatomical motion than one simply consisting

of a horizontal movement alone. By the time of the second shot, it is found that the required movement for tracking the target decreased by half, although some space would be needed for target reacquisition after the car cleared the tree obstruction. Thus the assassin, presumably after taking his crouch position in the sniper's nest, resting the rifle against the gun rest, was easily able to hit President Kennedy in the upper-torso (i.e., “center-mass”) [18]. Realizing that his target had not yet fallen (not hitting the sternum or spinal cord), and that he still had plenty of space given that the Secret Service had not yet taken action, he would take more time (about 5 seconds) before taking his third and last shot. As the limousine approached mid-Elm Street, its angular speed at the sniper position would be reduced to the point of becoming practically stationary (i.e., $\omega \approx 1.1^\circ/s$). This movement was about 7 times less than that required for the first shot, or the equivalent of taking 25–30 seconds to pivot from one's 12 to 1 o'clock. Note that although the limo did happen to slow down during this time (whether due to braking or not), this turns out not to have been a critical factor — had the car proceeded at a constant linear speed of 11.8 mph, the angular speed would have only been greater by 0.2°/s (i.e., $\omega \approx 1.3^\circ/s$). The ensuing shot at the near-stationary target would then, tragically, find its mark on the smaller silhouette kill-zone (i.e., the President's head).

Conspiracy proponents and Warren Commission skeptics are fond of proclaiming that Lee Oswald would not have had the necessary marksmanship skills (i.e., he was a “poor shot”) for carrying out the crime in Dealey Plaza [2, p. 20], presumably because of the moving target [3, pp. 494-495], but it would now seem such claims are naive. Unfortunately for history, this final shot was taken by a former US Marine at a virtually stationary target (1.1°/s), at a relatively close distance (81 m versus the 200 yards or 183 m encountered during his USMC marksmanship training), with a telescopic sight and gun rest (versus iron sights and no gun rest in the USMC), and so it should no longer come as any surprise that it would end up being the most accurate (and deadly) shot fired that tragic day.

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