II. The Number, Timing, and Source of the Shots Fired at the Presidential Limousine

A. Warren Commission Findings

(47) The Warren Commission concluded that three bullets had been fired at the Presidential limousine from the sixth floor, southeast corner window, of the Texas School Book Depository. Finding that the first pierced the President's neck, the Commission also indicated that "[a]lthough * * * not necessary to any essential findings * * *, there is very persuasive evidence from the experts to indicate that [this] * * * same bullet * * * also caused Governor Connally's wounds." (*12*) A second bullet caused a massive and fatal wound to the President's head; (*13*) a third bullet was believed to have missed the car and its occupants. (*14*)

(48) The Commission was unable to establish conclusively which of the three bullets missed, and hence the precise timespan of the shots was not definitively determined. By studying the Zapruder movie film, it found that the President's back wound occurred between frames 210 and 225, and that the head wound occurred at frame 313. (*15*) Based upon the 18.3 frame-per-second average rate of speed at which film was exposed in Zapruder's camera, the Commission then calculated that "there was an interval of from 4.8 to 5.6 seconds" between those two shots. (*16*) If the second bullet were the one that missed, then this interval was the timespan for all the shots. If, however, either the first or third bullet missed, the minimum timespan would have been 7.1 to 7.9 seconds (derived from the previous calculation of 4.8 to 5.6 seconds plus 2.3 seconds, the minimum time in which Oswald's Mannlicher-Carcano rifle could be fired). (*17*)

(49) To support its conclusion that the President's and Governor's wounds were caused by shots that were fired from the sixth floor, southeast corner window, of the Texas School Book Depository, the Warren Commission relied on an FBI reenactment. Using the Zapruder film as the point of reference, the FBI placed the limousine and its occupants in their approximate positions at the time of the shots and then determined the angle from the wound entry point on President Kennedy to "the end of the muzzle of the rifle positioned where it was believed to have been held by the assassin." (*18*) The average resulting angle of 17°43′30″, allowing for a downward street grade of 3°9′, was concluded by the Commission to be "consistent with the trajectory of a bullet passing through the President's neck and then striking Governor Connally's back * * *." (*19*)

(50) Although each of these findings has been criticized, the Commission's statement that the bullet which caused President Kennedy's neck injury was also responsible for Governor Connally's wounds has caused the most controversy. Warren Commission critics have asserted that in the Zapruder film, Governor Connally first reacts to his wounds at frames 234 or 238, 0.5 to 1.5 seconds after the President (who the

Commission found was struck between frames 210–225) and, therefore, could not have been hit by the same bullet. Moreover, given the 2.3-second minimum firing time for a Mannlicher-Carcano rifle, they assert that another gunman must have been involved in the assassination. (*20*)

(51) Critics have also questioned the Commission's "single bullet theory" because they find that, given the wounds, the relative alinement of the President and the Governor within the limousine was inconsistent with the path of a single bullet. (*21*) They claim that the Commission's trajectory analysis was self-serving, since it assumed a particular location for the gunman and then merely sought to verify that the angle from rifle muzzle to the limousine occupants was consistent with the trajectory of a bullet passing through the two men.

B. The Panel's Analysis

1. APPROACH

(52) In an effort to determine the number, timing, and source of the shots that were fired at the Presidential limousine, the Photographic Evidence Panel conducted the following studies:

(53) (a) The Zapruder film was studied for evidence of reactions to gunshots by both the limousine occupants and Dealey Plaza witnesses, and to determine whether the relative alinement of John F. Kennedy and John B. Connally within the limousine was consistent with the single-bullet theory. Still photographs pertinent to the single-bullet theory controversy were also reviewed;

(54) (b) The blurs in the Zapruder film were analyzed to determine if they could be attributed with precision to the cameraman's reflex reaction to the sound of gunshots;

(55) (c) A trajectory analysis was conducted under the direction of an aerodynamics engineer from NASA; and

(56) (d) Photographs of the Dealey Plaza environs in which it has been alleged that gunmen can be seen were subjected to photographic enhancement and analysis.*

2. VISUAL EVIDENCE DERIVED FROM OBSERVATIONS OF PERSONS IN THE ZAPRUDER FILM**

(*a*) *Issues*

(57) The Panel was requested by the committee to address, at a minimum, three questions:

(58) (a) When did Kennedy first show a reaction to some severe external stimulus?

(59) (b) When did Connally first show a reaction to some severe external stimulus?

(60) (c) Was the relative alinement of Kennedy and Connally within the limousine consistent with the single-bullet theory?

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*The results of this study are discussed at ¶241–346, *infra*.

** This section prepared under the direction of C. S. McCamy, Frank Scott and Bennett Sherman. For the related public hearing testimony of C. S. McCamy, 9/12/78, see HSCA–JFK Hearings, vol. II, pp. 142–54, 349–72.

(*b*) *Materials and procedures*

(61) The Zapruder film was studied with care at each of the panel's conferences.[1] At the final conference, which took place in July 1978, the film was closely scrutinized by more than 20 photographic scientists who were either members of the Panel or contractors responsible for much of the committee's laboratory work (i.e., photographic enhancement, restoration, etc.). At the Panel's request, a specially enhanced version of the Zapruder film had been obtained which stabilized and enlarged the images of Kennedy and Connally. The Panel was also given access to four frames which showed the Presidential limousine going behind a sign; these had previously been spliced out of the original Zapruder film. (*22*) Finally, computer assisted enhancements of relevant frames from the Zapruder film were made available to Panel members, but these were not reviewed until later.

(62) In total, the Zapruder film was viewed by this group on a frame-by-frame basis and at various speeds approximately 100 times.[2] A special analytical projector was used to facilitate this task. Because the quality of most of this film generally precluded analysis of facial expressions, primary emphasis was given to attempting to detect gross changes in body movements. As each frame was analyzed, proper consideration was given to the Zapruder film's exposure rate through the camera of 18.3 frames per second. (*23*) In this manner, changes in body movements between frames could be better understood and, at times, even quantified.

(63) After completing its review of the film the Panel took a vote with regard to each of the issues that had been raised by the committee.[3] The Panel's vote focused on those reactions to severe external stimuli that may have been suggestive of impacting bullets.

(*c*) *Conclusions*

(64) (a) By a vote of 12 to 5, the Panel determined that President Kennedy first showed a reaction to some severe external stimulus by Zapruder frame 207, as he is seen going behind a street sign that obstructed Zapruder's view.

(65) (b) By a vote of 11 to 3, the Panel determined that Governor Connally first showed a reaction to some severe external stimulus by Zapruder frame 224, virtually immediately after he is seen emerging from behind the sign that obstructed Zapruder's view.

(66) (c) By a vote of 15 to 1, the Panel determined that the relative alinement of President Kennedy and Governor Connally in the limousine was consistent with the single bullet theory.

(67) (d) At least two shots, spaced approximately 6 seconds apart, were fired at the Presidential limousine. Nevertheless, based only on

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[1] For references to Zapruder frames discussed herein, see JFK exhibits F–209–274, HSCA–JFK Hearings, vol. I, pp. 69–97.

[2] It is difficult to state this figure with precision because various segments of the film were continuously replayed while others received considerably less attention.

[3] Because the film was not viewed simultaneously by all participants, some of whom occasionally had to leave the room to perform other tasks, and as the voting was conducted at different times for each issue, the same number of votes was not cast on each issue.

its review of the reactions of persons shown in the Zapruder film, there was insufficient evidence to reach any conclusion concerning additional shots.

(d) Analysis

(68) The first reaction by any of the limousine occupants to a severe external stimulus begins to occur in the vicinity of Zapruder frames 162–167.* At this time, Connally is looking to his left, when his head begins a rapid, sudden motion to the right. In quantitative terms, he turns his head approximately 60° to his right in one-ninth of a second (a rate equivalent to a 540° rotation per second). He pauses momentarily and then executes a further 30° turn to his right, within an eighteenth of a second (again, a rate equivalent to a 540° rotation per second). This initial rapid motion, in which Connally has apparently turned his head to look behind him, is accompanied during the next approximately 20 frames by a more gradual 60° shift to the right of his upper torso. Although it is apparent that none of the limousine occupants has been shot at the time that Connally initiates this movement, the Panel considers these actions to be particularly significant because they were consistent with his Warren Commission testimony that he turned in response to having heard the first shot and was struck almost immediately afterwards. (*24*)

(69) During the period of Connally's initial rapid movement, however, no one else shows a comparable reaction. The President does not appear to react to anything unusual prior to Zapruder frame 190. The Panel observed, however, that at approximately this time, a young girl who had been running across the grass, beyond the far curb of the street where the limousine was traveling, suddenly began to stop and turn sharply to her right, looking up the street in a direction behind the limousine.

(70) At approximately Zapruder frame 200, Kennedy's movements suddenly freeze; his right hand abruptly stops in the midst of a waving motion and his head moves rapidly from right to his left in the direction of his wife. Based on these movements, it appears that by the time the President goes behind the sign at frame 207 he is evidencing some kind of reaction to a severe external stimulus. By the time he emerges from behind the sign at Zapruder frame 225, the President makes a clutching motion with his hands toward his neck, indicating clearly that he has been shot.

(71) Connally's movements as he emerges from behind the sign at Zapruder frames 222–224 also indicate that he is reacting to a severe external stimulus. He appears to be frowning, and there is a distinct stiffening of his shoulders and upper trunk. Then there is a radical change in his facial expression, and rapid changes begin to occur in the orientation of his head.

(72) In the subsequent frames, Kennedy and Connally appear to show simultaneous, reaction-type movements. There is less than a three-frame (0.16 second) delay in their movements.

(73) At frame 313, approximately 6 seconds (based on the 18.3 frames per second exposure rate of the Zapruder camera) after the

*Because this reaction was not perceived as a response to an impacting bullet, it was not adopted as one of the panel's conclusions.

President disappears behind the sign, his head is seen exploding from the impact of a bullet.

(74) Having noted the virtually simultaneous reactions displayed by Kennedy and Connally, the Panel proceeded to consider whether the two men's relative alinement in the limousine was consistent with the single-bullet theory. In this regard, the President is observed, between frames 170–190, to be sitting well to the right side of the limousine. Specifically, his right arm is extended over the chrome strip that runs along the side of the limousine. Governor Connally's rightward body orientation is clearly seen during these same frames. His body is situated much more toward the center of the limousine, as demonstrated by the amount of the rear seat that can be seen between President Kennedy and Governor Connally.

(75) This visual analysis was confirmed stereoscopically when computer enhancements of Zapruder frames 187 and 193 were examined in three dimensions as a stereo pair. Pairs of photographs, taken moments apart, may on occasion be viewed in a manner that gives rise to a three-dimensional image. When this occurs, the photographs are said to constitute a stereo pair.

(76) Stereoscopy may be explained as follows: Because human eyes are a short distance apart, each sees a slightly different aspect of any object within a distance of about 50 feet. These slightly different visual images are interpreted by the brain as clues to the relative distances of various parts of the object. This is called "stereopsis" or "stereoscopic vision." The two eyes see a single near object alined with different distant objects. This is known as parallax. This effect also contributes to the perception of depth.

(77) If two photographs are taken of the same nearby still scene and the camera is moved horizontally about 3 inches between the two exposures, the camera will record what would have been seen by two eyes (spaced about 3 inches apart), had they been in the same two places as the camera had been. When these photographs are viewed separately (so that one eye sees one photograph and another eye sees the other) by means of an optical device called a "stereoscope" or "stereo viewer," the visual system and the brain interpret the scene in depth, just as though the original scene were being viewed directly.

(78) The identical effect can be achieved with individual frames of a motion picture film such as the one taken by Zapruder. A motion picture film consists of a series of still photographs. A slight movement of the camera (that is, by about 3 inches) can result in individual frames being viewed as stereo pairs. In addition, even if the camera is held relatively still, a similarly slight movement by the object may give rise to stereo pairs of photographs. This is because, in relative terms, the effect is that of the camera moving in relation to a still object.

(79) When this technique was applied to the Zapruder film, the relative depth of Kennedy and Connally within the limousine could be carefully examined. On this basis, their relative alinement was found to be consistent with the single-bullet theory.

(80) The panel's conclusion of the relative alinement of the two men received further corroboration by an examination of still photographs and individual Zapruder frames.* It is further supported by the trajectory analysis described in the following section.

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*In this regard, the Panel adopts the analysis set forth in ¶ 158–165 *infra*.

3. THE PANNING ERROR—BLUR ANALYSIS OF THE ZAPRUDER FILM*

(*a*) *Issues*

(81) (a) Can any of the panning errors indicated as blurs or "jiggles" on the Zapruder film reasonably be attributed to the photographer's involuntary startle reaction to the sound of gunshots?
(82) (b) If so, is it possible to determine from such panning error blurs the number, and to estimate the timing, of the shots that were fired at the Presidential limousine?

(*b*) *Procedures and materials employed*

(83) Originally, a blur study of the Zapruder film was to involve an analysis of not only the Zapruder, but also the Nix and Muchmore films, to determine whether startle reactions by the photographers were present and simultaneous for each photographer. Nevertheless, neither the Nix nor Muchmore films included any extensive footage prior to the time of the head shot. Thus, only the Zapruder film, which showed the entire motorcade scene immediately prior to and during the assassination, was subjected to this analysis.**
(84) The measurement of blur, or jiggle, essentially involved a measure of Zapruder's error in panning his camera as he filmed the Presidential limousine. Two sets of measurements were made independently by Photographic Evidence Panel members William Hartmann and Frank Scott. Hartmann measured the length of images of small highlights on the Presidential car in each frame; these were generally small and round on the sharpest frame but highly elongated on frames that were blurred by camera motion during the time that the shutter was open. The amount of elongation was measured to determine the panning error. (See fig. II–1.)

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*This section prepared under the direction of William K. Hartmann. For Dr. Hartmann's related public hearing testimony, 9/11/78, see HSCA–JFK Hearings, vol. II, pp. 4–16.

**In addition, the Nix and Muchmore films were taken from a distance of about 2.7 and 2.1 times, respectively, further away from President Kennedy than the Zapruder film.

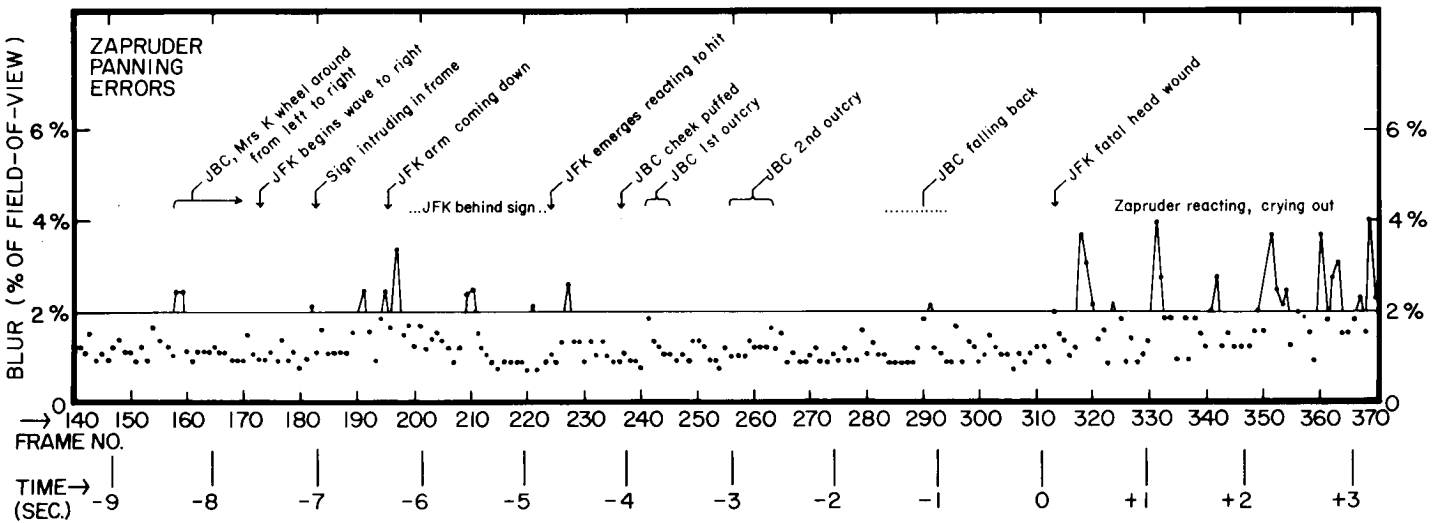

FIGURE II-1.--Amount of blur on each frame of Zapruder film as measured by W. K. Hartmann. Blur (elongation of images) is presented in terms of percentage of width of a whole frame. Large blurs represent jerking of camera, suggesting a startle reaction.

(85) Scott followed background details from frame to frame. These details indicated a direction in which the camera pointed during each frame. The sequence of these camera point directions would have defined a smooth, relatively straight line had the camera panned in a perfectly uniform manner (see fig. II–2, JFK exhibit F–371); discrepancies were revealed by erratic spacing of camera pointing directions (see fig. II–3, JFK exhibits F–372–373).

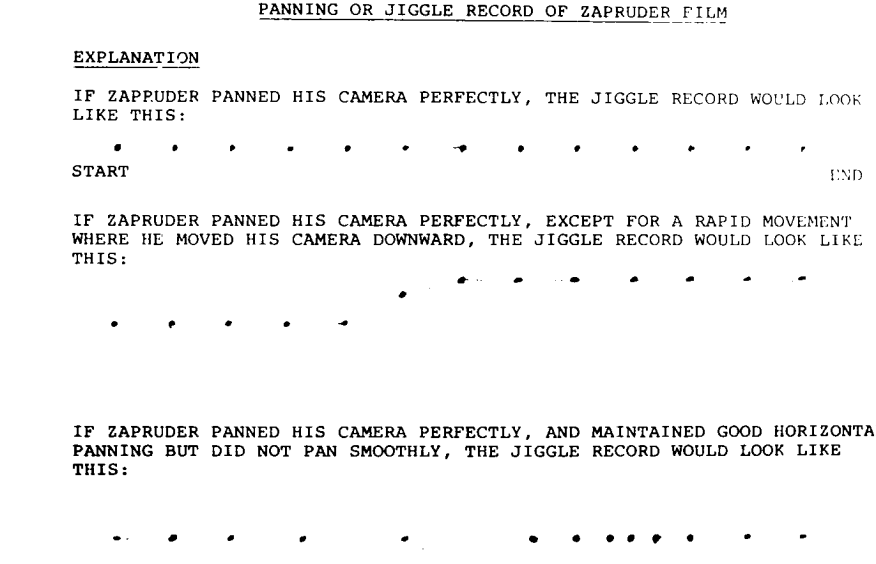

FIGURE II–2.—Illustration of technique used by Frank Scott. If Zapruder had made no panning errors, the background points from frame to frame would have been plotted as illustrated.

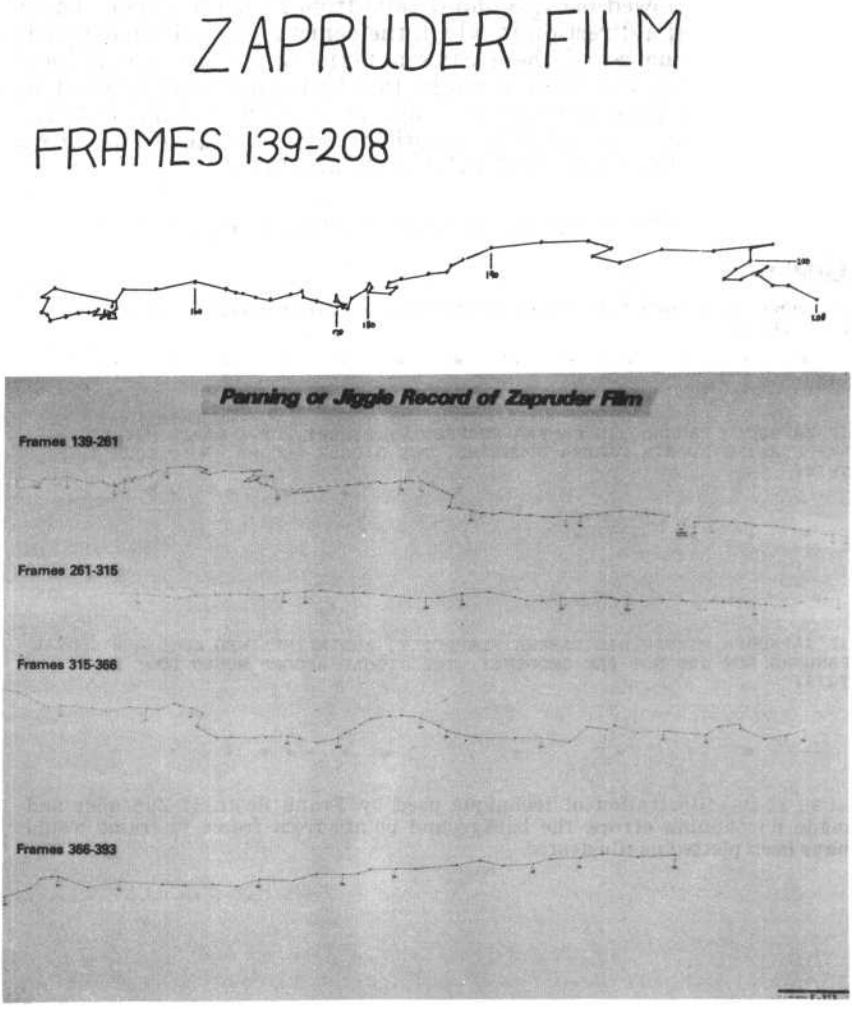

FIGURE II–3.—Actual plotting of background points from frame to frame by Frank Scott, showing Zapruder panning errors. Illustration on top, showing only frames 139–208, is enlargement of portion of illustration on bottom.

These were transformed into quantitative measurements by a vector subtraction process: A 20-frame running average of the rate of angular motion was used to predict the point where the camera should be aimed in frame *n*, based on the place where it was directed in frame *n–1*. A subtraction was then made between the *n–1* to *n* vector which should have appeared and the vector that actually did appear. This vector difference was then measured to determine the panning error between frames.

(86) The results of these measurements were then plotted to illustrate visually the times of greatest panning error in a manner similar to Figure II–1. (See fig. II–4.) In both Figure II–1 and Figure II–4, a threshold line was then drawn horizontally across the graph to separate visually the areas of greatest (i.e., unusual) blur from the "noise", or the normal panning errors that occurred throughout the filming simply because the camera was hand held. Any such threshold line, of course, must to some extent be arbitrarily placed. The extent of blur that resulted from an unusual external stimulus (e.g., a gunshot) may not, therefore, always be precisely delineated by the line. Zapruder's true startle reactions may have begun a frame or two earlier, or later, than indicated by the placement of the threshold line that was chosen, but blurs above the threshold line are well above the average.

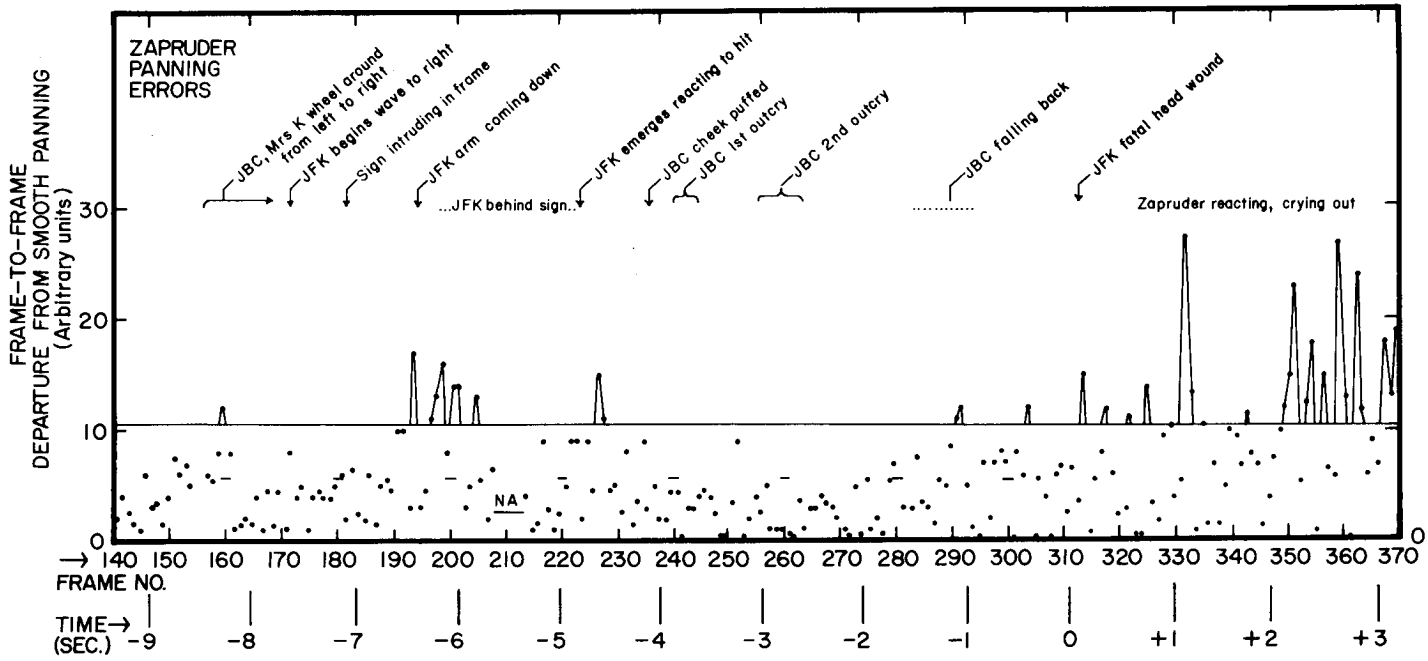

FIGURE II-4.—Errors in smooth tracking, as measured from one frame to another by Frank Scott. (Measures were reduced from Scott's graphs to numerical measures presented here by W. K. Hartmann, by method described in text.)

(87) Following our measurement of blur by these two different methods of the panning errors, the results of Luis Alvarez' study, reported in the *American Journal of Physics*, vol. 44, p. 813 (1976), were also reviewed. Instead of measuring the blur itself, Dr. Alvarez measured the difference in blur between frames and calculated the rate of change in blur, thus providing a sensitive record of any unusually erratic movement by Zapruder. All three sets of measurements were plotted on a single graph and used in the subsequent analysis. (See fig. II–5.)

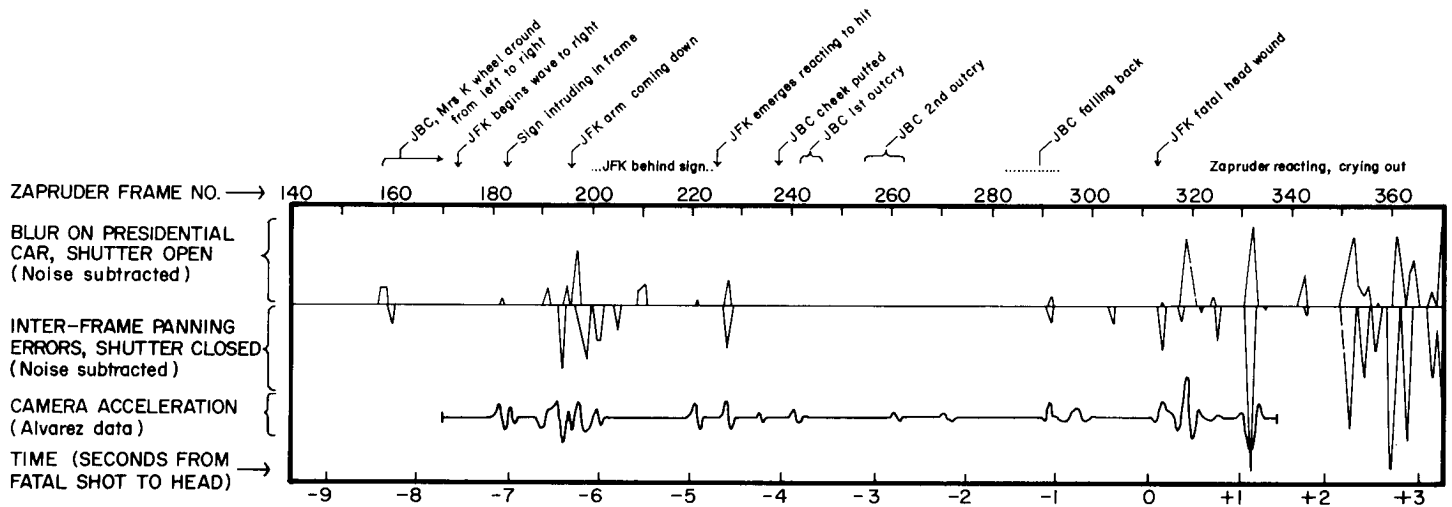

FIGURE II–5.—A comparison of the three independent records of largest blurs or tracking errors, in the Zapruder film, as derived by W. K. Hartmann (top, above line), Frank Scott (top, below line), and L. Alvarez (bottom). Magnitude of blur or panning error is indicated by length of curve upward or downward along direction of vertical axis. Frame numbers and times in seconds are given at top and bottom along horizontal axis.

(88) To assist in the analysis, a time-scale in seconds was added to figures II–1, 4 and 5. The zero point in the time-scale was chosen to coincide with the moment when the trigger was pulled on the fatal head shot. This was estimated to have been at frame 310, based on estimates of the average running speed of Zapruder's camera in conjunction with other scientific evidence.

(89) Specifically, Zapruder reported that his camera was fully wound when he started filming the motorcade as it turned onto Elm Street. In 1964, the FBI tested the camera and found that during the first 30 seconds of its operation (after being fully wound) Zapruder's camera ran at between 18.0 and 18.5 frames per second, with the average estimated to be 18.3. Note that the range 18.0 to 18.5, indicates a range of 3 percent uncertainty in all time intervals measured from the Zapruder film. (*25*)

(90) Fragmentary material from the President's head is seen flying upward and outward in frames 313 and 314. The fragments are already airborne and in motion in frame 313. Extrapolation backwards indicates that the explosion began in frame 312 rather than 313, since this would be the frame nearest to the moment when the fragments left the head. Other scientific evidence, such as wound measurements, and trajectory analysis, indicated that the fatal head shot was fired from a Mannlicher-Carcano rifle located in the southeast corner window of the sixth floor of the Texas School Book Depository.(*26*) The distance from that window to the limousine at frame 312 is approximately 265 feet.(*27*) Since a Mannlicher-Carcano bullet travels at approximately 2000 feet per second,(*28*) the bullet flight time would have been 0.13 second, or the passage of approximately 2.4 frames in Zapruder's camera. Subtracting these two frames from frame 312, it is apparent that the fatal shot was fired at approximately frame 310.

(91) Using frame 310 as the time of the trigger pull, it is possible to determine that the sound from that shot would have reached Zapruder at frame 313–314: Zapruder was standing approximately 270 feet from the Texas School Book Depository window, sound travels slightly more than 1,100 feet per second. (*29*) and the sound of the shock wave from the bullet itself reached Zapruder slightly before the sound of the muzzle blast from the window.

Finally, the pattern of jiggles that was discovered was compared with the results of the committee's acoustics study. The correlation between the jiggle analysis and the acoustics test is treated separately in an addendum to this report.

(*c*) *Conclusions*

(92) 1. Two pronounced series of jiggles or blurs on the Zapruder film, one during frames 189–197, a time when other visual evidence suggests that President Kennedy was first shot, (*30*) and another during frames 312–334, following impact of the head shot, may reasonably be attributed to the photographer's startle reaction to the sound of gunshots.

(93) 2. The timing of the shots associated with these two sets of blurs can reasonably be determined to be approximately 6 to 7 seconds apart.

(94) 3. Other blurs which might relate to gunshots, appear on the

film both between these two sets and elsewhere. Due to the absence of other visual evidence associated with these blurs, the Panel made no finding as to their cause.

(*d*) *Analysis*

(95) As noted above, the sound from the fatal head shot would have reached Zapruder at frame 313–314. Frame 313 is also the moment when the head explosion became visible to Zapruder. The largest blurs or jiggles on the three independent data sets of Hartmann, Scott, and Alvarez occur between frames 312 and 334. Because some of the jiggles are minor and appear on one or two of the data sets but not all three, it is difficult to determine exactly when the reaction in question actually started. The Hartmann data set shows a very large blur in frame 318 with smaller ones at 313 and 314. (See fig. II–1.) The Scott measurements show several smaller jiggles between 313 and about 324. (See fig. II–4). The Alvarez data show the largest acceleration of camera motion at 315, but with a cluster of motions from 312 to 322. (See fig. II–5.) Empirically, it appears, therefore, that Zapruder's startle reaction apparently occurred about 1 to 5 frames, or about 0.05 to 0.3 seconds after the sound reached him.

(96) In fact, the Panel found some empirical corroboration for this conclusion. Startle reaction times in response to the sound of gunshots were measured in the experimental work of Landis and Hunt in 1939. (*31*) For "head movement," "movement of neck muscles," and "initiation of arm movement," Landis and Hunt found that the reaction time was 0.06 to 0.2 second (i.e., 1.1 to 3.7 frames). (*32*) Thus, these much earlier experimental findings support the conclusion that the film actually records Zapruder's startle reaction to the fatal shot immediately after Zapruder heard the sound of the shot and saw the head impact through his viewfinder.

(97) In all three data sets, the second longest and second greatest (in terms of magnitude of blur or jiggle) disturbance in camera panning motion occurs between frames 189 and 197. Since our objective is to estimate the time the shots were fired, the blurred frames of most interest are those from the jiggle's beginning to its peak rather than to its decline. For the various data sets, the time from the first strong increase in blur to the maximum blur or jiggle is as follows: Hartmann, 191–197; Scott, 193–194; and Alvarez, 189–195. (See figs. II–1, II–4, and II–5.)

(98) Assuming that a shot from the sixth floor Texas School Book Depository window caused this reaction (a distance at this point in time of approximately 165 feet from the limousine) (*33*), and that Zapruder's reaction was again almost immediate (within 1 to 4 frames after hearing the shot), it is possible to calculate backward (adding sound travel time to Zapruder of 4 frames, to reaction time of 1 to 4 frames), and determine that the shot may have been fired between frames 181 and 192, and impacted in the limousine between frames 182 and 193. This conclusion is reinforced somewhat by the Photographic Evidence Panel's visual observation of the Zapruder film which reflected a reaction by President Kennedy to some severe external stimulus by frame 207 when the President disappears behind a sign frame. (*34*) Assuming a uniform reaction time in both cases by Zapruder, and that both shots originated in the same location (the

sixth floor window), the trigger pull on this shot would have preceded that of the fatal head shot by approximately 6.3 to 6.9 seconds (minimum, 313–197 over 18.5 equals 6.3; maximum 313–189 over 18.0 equals 6.9).*

(99) The blur or jiggle results have been examined for other blur episodes that possibly correlate with additional gunshots. The three next largest episodes of blur are listed in table 1, in which the largest and second largest blur episodes discussed above are designated A and B. The third, fourth, and fifth largest blur episodes, which are similar to one another in magnitude, are listed respectively as C, D, and E.

(100) It is difficult to determine with certainty whether any of these represents an additional shot or shots. Blur episode C, detected by all three analysts, occurs at frames 220–228, just before movements of Governor Connally in which his cheeks suddenly puff out and his face contorts in a grimace, followed by two apparent outcries in which his mouth opens wide in what appears to be a shout of pain.

(101) Another shot could have caused blur episode D at frames 158–160. It occurs much earlier in the motorcade than had been considered possible for a shot by either the Warren Commission or most Warren Commission critics. Nonetheless, this brief blur was detected by both Hartmann and Scott; Alvarez published no data for such an early part of the motorcade because he used the Warren Commission volumes which do not even reproduce Zapruder frames earlier than the mid-170's. The most interesting thing about this hypothetical shot is that Mrs. Kennedy and Governor Connally testified before the Warren Commission and Governor Connally testified before the select committee that they turned to their right when they heard the first shot, (*35*) and both are seen in the film beginning a turn to the right immediately after this hypothetical shot. This appears particularly striking in the case of Governor Connally, whose head turns from midleft to far right in less than half a second, beginning at frame 162.

(102) A fifth episode (E) possibly associated with a shot occurs at frames 290–293. Although it contains a very small blur detected by both Hartmann and Scott, as well as a more substantial blur in Alvarez' data, the Panel found no visual indications of reactions to a shot by the limousine's occupants coinciding with this segment of blur in the film.

(103) Other jiggles or blurs were present in the photographic record. (See fig. II–5.) Without further data, however, the magnitude and duration of these jiggles, as those with characteristics of C, D, and E, are insufficient to warrant any conclusion concerning the number and timing of any additional gunshots.

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*Assuming a uniform reaction time, and a uniform distance of Zapruder from the shooter, it is possible to ignore delays caused by sound travel from the shooter to Zapruder and Zapruder's reaction time in calculating the spacing of the two shots, since any assumed value for such delays would be self-canceling in the calculation.

TABLE 1.—BLURS IN ZAPRUDER FILM

Relative magnitude of blur episode	Designation of blur episode	Shown by	Frames showing blur onset (beginning to maximum)
Largest	A_1	Alvarez	312–318
		Hartmann	313–318
		Scott	313–314
	A_2	Alvarez	330–334
		Hartmann	331–332
		Scott	331–333
2d largest	B	Alvarez	189–195
		Hartmann	191–197
		Scott	193–194
3d largest [1]	C	Alvarez	220–228
		Hartmann	227
		Scott	226–228
4th largest [1]	D	Hartmann	158–159
		Scott	158–160
5th largest [1]	E	Alvarez	291–293
		Hartmann	290–291
		Scott	290–292

[1] About equal.

ADDENDUM

Comparison With Results of the Acoustics Analysis

(104) The acoustics analysis suggests the possibility of four shots, the first, second, and fourth originating from the Texas School Book Depository and the third having been fired from the grassy knoll. (*36*) This appendix discusses the extent of agreement between the acoustic timings and the major blurs on the Zapruder film.

(105) A first step in comparing the acoustic results to the blur analysis would be to line up one of the shots indicated by the acoustics analysis with the known fatal head wound to the President. This cannot be shots No. 1 or No. 2 from the acoustics analysis because the President's reaction to the back wound, at approximately frame 200 would then occur before any shooting. Therefore, the fatal head wound had to be shot No. 3 or No. 4. It is improbable that the fatal head shot was shot No. 3 because the acoustics analysis places this shot as coming from the grassy knoll, while the medical and other scientific evidence indicates that the President's head was struck from the rear. (*37*) The fatal head shot, therefore, was probably the last shot identified in the acoustics analysis.

It is thus a simple step to work backward in time from that final shot to derive the times that Zapruder heard shots based on the acoustics results. The acoustics report states that the time intervals between the four shots recorded on the Dallas Police Department tape are 1.57, 5.63, and 0.71 seconds respectively, (*38*) but that the Dallas Police Department recorder was running approximately 5 percent too slow. (*39*) Adjusting for this 5-percent error, the actual spacing of the shots to the nearest one-tenth second would therefore be 1.6, 6.0, and 0.7 seconds.

(106) As noted earlier, the FBI tested Zapruder's camera in 1963. They found that its speed varied from 18.0 to 18.5 frames per second during the first 30 seconds of its operation (after being fully wound), and then ultimately decreased to 17.6 frames per second before it completed the next 30 seconds of its operation. Because Zapruder said his

camera was fully wound when he began filming the motorcade, it may be assumed that the camera ran between 18 and 18.5 frames per second during the approximately 8 seconds of the assassination. Using these parameters for film speed, and allowing for sound and bullet travel times, the frames exposed when the bullets would have reached the limousine, and when Zapruder would have heard the muzzle blast, can be calculated. (See cols. 3 and 4 of top of table II.)

(107) In constructing and then using table II, a note of caution is appropriate: Any calculation of the frames exposed, based upon a correlation with the sound impulses on the Dallas Police Department tape, should not be presumed to be absolutely precise because only the average, and not the precise, running speeds for the camera are known, and the tape speed adjustment of 5 percent is similarly only an average. Thus, table II reflects mathematical calculations of frame numbers utilizing the available averages, that is, a tape speed adjustment of 5 percent (although the tape may have actually been closer to 4½ percent or 5½ percent slow at times) and the parameters of 18.0 to 18.5 frames per second camera speed. The actual frames when an event occurred may have been a frame or two different than the calculations based upon such estimated averages.

(108) As can be seen from columns 3 and 6 of the table, there is good correlation for shots 1, 2, and 4, where in each case the blurs occur when the acoustics data reflect Zapruder would have heard the shots. On the other hand, there is no correlation (except possibly for the Scott measurements) for shot No. 3, since the blur at 289–293 precedes the arrival of sound at Zapruders' location and thus could not have been a product of his startle reaction to that sound.*

(109) The same calculations and comparisons can be made using the assumption that the third shot (the one from the grassy knoll) caused the head wound at frame 312. This process is reflected in the lower portion of table II. Here there are blurs following each shot, the first two lagging behind Zapruder's hearing of the sound by 9 to 12 frames (½ to ⅔ second), and the second two immediately following his hearing the sound.

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*There is one relatively small panning error between frames 300 and 305 detected by Scott's technique. See figure II–4.

TABLE II

IF THE FOURTH SHOT CAUSED THE FATAL HEAD WOUND					
ACOUSTICS STUDY				PANNING ERROR - BLUR ANALYSIS	
Unadjusted Tape Time	Adjusted Spacing *	Frames Exposed When Zapruder Heard Shots	Frames Exposed At Bullet Impact	Blur Episode**	Blurred Frames
137.70	1.6	159-165	157-161	(D)	158-160
139.27	6.0	191-194	188-191	(B)	189-197
144.90	.7	296	295-296	(E)	290-293
145.61		313-314	312	(A_1)	312-318
IF THE THIRD SHOT CAUSED THE FATAL HEAD WOUND					
137.70	1.6	175-181	173-177	(B)	189-197
139.27	6.0	208-210	205-208	(C)	220-228
144.90	.7	312	312	(A_1)	312-318
145.61		330	328-329	(A_2)	330-334

* These times are the adjusted spacing of the sound impulses on the Dallas Police Department tape recording, and not the spacing of trigger pull or bullet impact times, which would vary somewhat from these times based upon the distances between the weapons, the limousine, and the motorcycle microphone that transmitted the sounds.
** The blur episodes are taken from Table I.

4. THE TRAJECTORY ANALYSIS*

(a) Introduction

(110) A trajectory is the path taken through space by an object such as a missile or bullet. In general, the trajectories of missiles are curved because of factors such as gravity and aerodynamic forces. Nevertheless, in the case of high speed bullets traveling short distances, the curvature is typically slight. (*40*) In such cases, the effect of aerodynamic forces is small both because the projectile flies almost perfectly nose-on through the air and because any small side-to-side movements tend to cancel one another by virtue of the bullet's spin. (*41*) The effect of gravity is similarly slight and can be easily calculated. For a total flight path of 200 feet at 2000 feet per second (the speed of a bullet from a moderate performance rifle), the time in flight is one-tenth of a second. During this period, gravity deflects the flight path only two inches. (*42*) A high performance rifle bullet would be deflected even less because it is traveling faster and its time in flight is shorter. It is, therefore, permissible to characterize the trajectory of each bullet fired at the President as a straight line extending between rifle and victim.

(b) Issues

(111) In connection with the trajectory analysis, the Panel undertook to answer three questions:

* This section was prepared under the direction of Thomas N. Canning, with the assistance of Clyde C. Snow and C. S. McCamy. For the related public hearing testimony of Canning and McCamy, see HSCA-JFK Hearings, 9/12/79, vol. II, pp. 142-203.

(112) 1. What were the trajectories of the bullets that struck the President?
(113) 2. Is the trajectory of the bullet that caused the President's back and neck wounds consistent with the single bullet theory?
(114) 3. Given the trajectories, from where were the bullets fired?

(c) Procedures

(115) A straight line trajectory can be constructed once any two points the missile is known to have passed have been established. In the present study, the inshoot and outshoot wounds inflicted by the bullets that struck President Kennedy and Governor Connally were used as the two points.
(116) In order to calculate the trajectory based on these wound pairs, it was necessary to establish the position of each entry and exit point in space at the time it was inflicted. This requires that three determinations be made:
(117) 1. The location of the wounds relative to recognizable reference features of the victim had to be established. Ideally, this information could be expressed in terms of a measured distance left or right from the midplane of the body along well-defined directions in reference to clear external features such as an ear or elbow.
(118) 2. It was necessary to determine the angular orientation of the wounded part of the victim relative to his immediate surroundings—that is to say, in what direction he was facing, what his inclination was forward or backward, and to which side he was leaning and by how much.
(119) 3. It was necessary to know where the victim was located relative to his surroundings, i.e., the location of the victim within the limousine and the location of the limousine relative to known landmarks in Dealey Plaza.
(120) The requisite information for undertaking this particular trajectory analysis could not be accurately obtained from any single source. Consequently the committee asked its various scientific consultants to provide input from their areas of expertise. The Forensic Pathology Panel was responsible for providing, to the extent possible, the precise locations of the wounds sustained by Kennedy and Connally.* It relied on enhanced postmortem photographs and X-rays of President Kennedy which were produced by the Photographic Evidence Panel. Enhanced photography was further used in the effort to determine the precise orientation of President Kennedy at the time of the assassination. The Photographic Evidence Panel also assisted in the interpretation of motorcade photographs of Kennedy and Connally and in providing photogrammetrically derived measurements of critical aspects of the photographs. Finally, the actual placement of the presidential limousine in the Dealey Plaza area at the time of the

*While the Forensic Pathology Panel did provide this information, the actual measurements related to wound locations were determined by the NASA scientist who was responsible for supervising the trajectory project. He was in frequent consultation with members of the Forensic Pathology Panel and with forensic anthropologists from both the FAA's Civil Aeromedical Institute and the Smithsonian Institute.

shots was established through a photogrammetric analysis conducted by the U.S. Geological Survey (USGS).[1] (*43*)

(121) All the preceding information was compiled under the supervision of Thomas N. Canning, an engineer from the Space Project Division of NASA, who then was responsible for constructing the actual trajectories. In contrast to the trajectory analysis performed by the Warren Commission, (*44*) the investigative procedures and analyses in this instance were governed by the hypothesis that there was no other evidence (e.g., the discovery of bullet cartridges and a rifle in the Texas School Book Depository) concerning the source of the shots.

(122) Although all of the available scientific evidence indicated that President Kennedy and Governor Connally were struck by a total of two bullets, one hitting President Kennedy in the back and continuing through to enter Governor Connally after exiting President Kennedy's neck, and the other hitting President Kennedy's head, three different trajectories were constructed: One based on the entry and exit wounds to President Kennedy's head, another on President Kennedy's back-neck wounds, the last on the exit wound to President Kennedy's neck and the entry wound to Governor Connally's back.[2] The first two trajectories were constructed for the purpose of determining whether the two shots were fired from the same location and the third to determine whether the relative alinement of President Kennedy and Governor Connally in the limousine was consistent with the single bullet theory.

(*d*) *Conclusions*[3]

(123) *Kennedy's head wounds.*—The bullet that caused Kennedy's head wounds at Zapruder frame 312 came from a point 29° to the right of true north from the President. The bullet was descending at an angle of 16° below horizontal as it approached him. This trajectory intercepted the plane of the Texas School Book Depository approximately 11 feet west of the southeast corner of the building at a point 15 feet above the sixth floor windowsills.

(124) *Kennedy's back and neck wounds.*—The bullet that caused President Kennedy's back and neck wounds came from a point 26° to the right of true north from the President. It was descending at an angle of 21° below horizontal as it approached him. Extending this trajectory from the position President Kennedy occupied at the time of Zapruder frame 190, the trajectory intercepted the plane of the Texas School Book Depository approximately 11 feet west of the southeast corner and 2 feet lower than the sixth floor windowsill.

(125) *Kennedy neck and Connally back wounds.*—The bullet which caused President Kennedy's neck wound and Governor Connally's back wound came from a point 27° to the right of true north from the Presi-

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[1] USGS was asked to determine the position of the limousine at times corresponding to Zapruder frames 150, 190, 285, 313, and 413; however, because some of these frames did not provide the required visual coordinates, the nearest frame with sufficient reference points was used.

[2] No trajectory analysis based solely on the wounds suffered by Connally was attempted because the bullet that struck him in the back hit at least two bones (at oblique angles) and was consequently significantly deflected.

[3] Explanatory diagrams supporting these conclusions are set forth in the analysis section of this report.

dent and was descending at an angle of 25° below horizontal.

(126) Given the position of the two men at the time of Zapruder frame 190, the trajectory intercepted the plane of the Texas School Book Depository 2 feet west of the southeast corner and 9 feet above the sixth floor windowsill. Because this trajectory falls within the trajectory range established when President Kennedy's back-neck wounds are used as the reference points for the trajectory line, the Panel concludes that the relative alinement of President Kennedy and Governor Connally within the limousine is consistent with the single bullet theory. Further, since each of these trajectories intersects the plane of the Texas School Book Depository in the vicinity of the southeast corner of the sixth and seventh floors, it is highly probable that the bullets were fired from a location within this section of the building.*

(*e*) *Analysis*

(*1*) *The head wound case**

(127) To determine this trajectory, the Panel first had to locate the entrance and exit head wounds as precisely as possible. Figures II–6 and II–7 show where the fatal bullet entered the back of President Kennedy's head at a point 9.0 centimeters above the external occipital protuberance. (*45*) This distance was measured on postmortem X-rays from point to point. The entry point is 1.8 centimeters to the right of the midplane of his skull. The bullet passed forward through his head and exited at the right coronal suture at a point 11 centimeters forward of the entry wound and 5.5 centimeters to the right of the midplane. This exit point was 1 centimeter lower than the entrance wound, using as the exterior vertical reference a line drawn through the President's brow and upper lip. Thus the bullet was traveling 18.6° to the right relative to his midplane and 5.0° downward relative to his facial axis.

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*The above conclusions differ to some extent from the testimony given by Thomas N. Canning before the House Select Committee on Assassinations on Sept. 12, 1978, in each case, the differences reflect new information or analysis resulting from work concluded subsequent to the presentation of preliminary findings at the heading.

*The interpretation of the head wounds used in defining trajectory reported in testimony on Sept. 12, 1978 differs from this report because the final illustration from the Forensic Pathology Panel showed the exit wound to be 1 centimeter lower than the entrance, rather than level with it as had been concluded earlier. Thus, the resulting trajectory is somewhat steeper.

LOCATION OF HEAD WOUNDS IN PRESIDENT KENNEDY

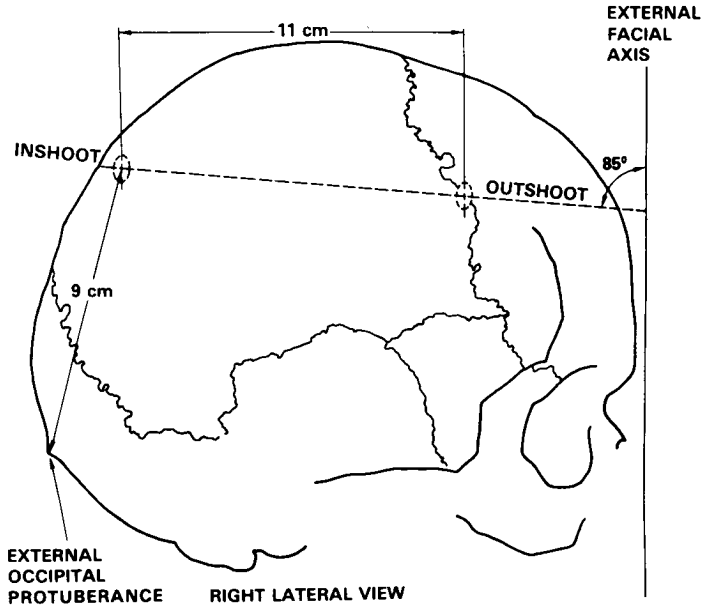

FIGURE II-6

LOCATION OF HEAD WOUNDS IN PRESIDENT KENNEDY

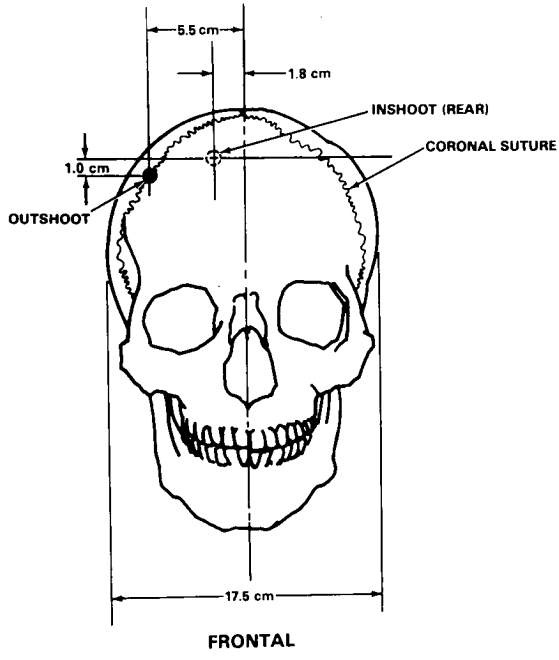

FIGURE II-7

(128) Once these wound locations were established, derivation of the bullet's trajectory still required knowledge of the orientation of Kennedy's head relative to Dealey Plaza. Establishing this relationship from the photographs was most easily accomplished in two steps: (1) finding the position of Kennedy's head relative to the line of sight to Zapruder's camera, and (2) accounting for the orientation of that line relative to the entire Dealey Plaza area.

(129) The Zapruder and Nix films showed the position both of Kennedy's head and of suitable reference structures in the field of view such as walls, street lights, and curbs. Since Kennedy's head is seen exploding in frame 313 of the Zapruder film, frame 312, which was exposed 0.055 seconds earlier, was considered to be the most important photograph available for this aspect of the trajectory analysis. (See JKF exhibit F–254.)

(130) The key features to be analyzed in frame 312 with respect to determining the orientation of Kennedy's head, were the lateral and vertical position of his right ear relative to the outline of the head and the overall relationship between his ear, nose and eyebrow. Rather than basing the analysis on a purely subjective interpretation, orientation was determined by comparing these features, as they appeared in an enhanced print of Zapruder frame 312 (see fig. II–8, JFK exhibit F–134), with a series of calibration photographs of a replica of Kennedy's head prepared by the Civil Aeromedical Institute of the

FIGURE II–8

FAA's Aeronautical Center.* These calibration photographs were taken from many carefully measured aspects (lines of sight), including several which closely approximated the relative location of Zapruder's camera at frame 312. (See fig. II–9, JFK exhibit F–141.)

FIGURE II–9.—Calibration photograph corresponding with Zapruder frame 312.

(131) After studying those protographs most closely approximating the correct aspect, it was possible to determine, by comparing the positions of such features as Kennedy's ear relative to other parts of his head, the aspect from which Zapruder's camera viewed Kennedy. On this basis, it was determined that Kennedy was turned partially away from Zapruder—approximately 25° past the 90°, or profile, direction. His head was tilted away from Zapruder by about 15°, and he appeared to be nodding forward by about 11° (clockwise, as viewed by Zapruder).

(132) In order to obtain a similar set of relationships relative to landmarks in Dealey Plaza, it was necessary to establish the orientation and position of this line of sight. Its direction and the point where it intercepts Kennedy's head were determined by drawing a line on a scaled map of Dealey Plaza between Zapruder, whose position had been derived from other photographs and testimony, and Kennedy at the geographic position on the street corresponding to the limousine's location at the time that Zapruder frame 312 was exposed. The latter was determined by relying on the photogrammetric

* The construction of the replica and the taking of the calibration photographs are described in addendum A, at pars. 169–176 *infra*.

analysis of the USGS. (*46*)* (See fig. II–10, JFK exhibit F–133.) The slope of this line was calculated by considering the relative heights of both the pedestal on which Zapruder was standing and of the street at the point where the limousine was located at frame 312, and then measuring the distance between Zapruder and Kennedy.

(133) The pedestal on which Zapruder stood was 12 feet above the point on Elm Street occupied by Kennedy at the time of Zapruder frame 312. When both the height at which the camera was held and the height of Kennedy's head above the street were considered (about 5 feet and 4 feet, respectively), the camera was determined to have been about 13 feet higher than Kennedy. The distance between Kennedy and Zapruder was about 70 feet at the time of the fatal shot. (See fig. II–10, JFK exhibit F–133.) Given this height difference and the distance between the two men, a line of sight downward from Zapruder to Kennedy was computed to be at an angle of 10°.

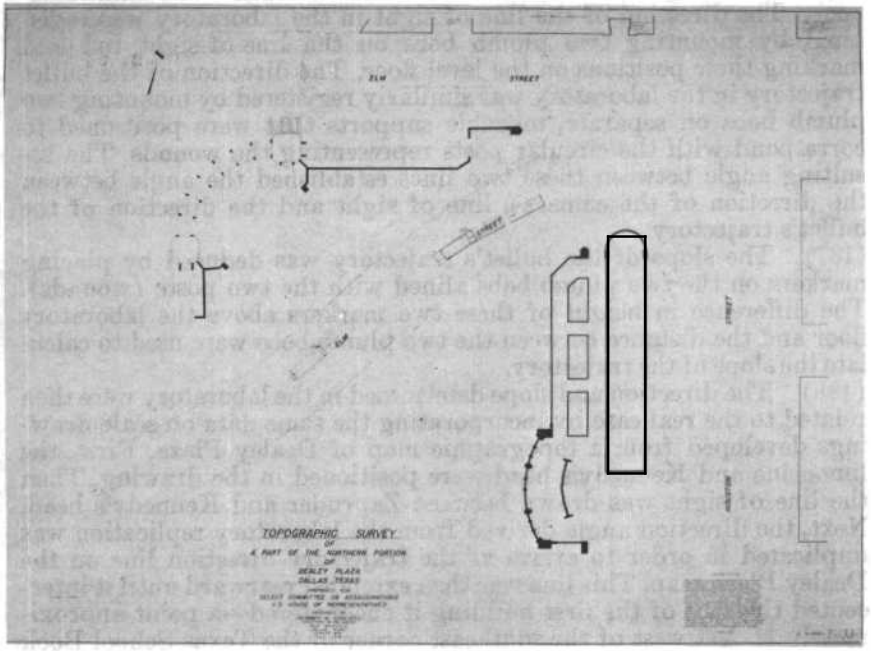

FIGURE II–10

(134) Once these factors had been established, the geometric relationship between the line of sight from Zapruder's camera and the trajectory line defined by the inshoot and outshoot wounds in Kennedy's head was determined.

(135) A physical reconstruction, consisting of a wooden mockup based on the photographic analysis of Zapruder frame 312, was used.

*Because Zapruder frame 313 provided better reference points, the USGS used that frame to determine the location of the limousine. Based on the limousine's estimated average speed, an adjustment of 1 foot was made to locate the vehicle at frame 312.

In the mockup, the camera line of sight was represented by a straight dowel. The midplane of Kennedy's head was represented by a flat piece of wood to which the line-of-sight dowel was affixed in a manner reflecting its relative slope and direction. A second straight dowel was installed vertically at the front of the midplane to represent the external facial axis defined by the forehead and upper lip. Finally, to simulate the location of the entry and exit wounds, two short posts were fastened to the midplane 11 centimeters apart and extending 1.8 and 5.5 centimeters outward on the same side as the line-of-sight rod. These posts were fitted with circular tips—one open and the other solid—to serve as sighting points. The positions of the posts relative to the facial axis and line-of-sight rods duplicated the positions of the wounds as located by the Forensic Pathology Panel.

(136) This assembly was then supported on a photographer's tripod in a laboratory so as to duplicate the slope of the line of sight of Zapruder's camera and the inclination of the facial axis simultaneously. The direction of the line of sight in the laboratory was registered by mounting two plumb bobs on the line-of-sight rod and marking their positions on the level floor. The direction of the bullet trajectory in the laboratory was similarly registered by mounting two plumb bobs on separate, movable supports that were positioned to correspond with the circular posts representing the wounds. The resulting angle between these two lines established the angle between the direction of the camera's line of sight and the direction of the bullet's trajectory.

(137) The slope of the bullet's trajectory was deduced by placing markers on the two plumb bobs alined with the two posts (wounds). The difference in height of these two markers above the laboratory floor and the distance between the two plumb bobs were used to calculate the slope of the trajectory.

(138) The direction and slope determined in the laboratory were then related to the real case by incorporating the same data on scale drawings developed from a topographic map of Dealey Plaza. First, the limousine and Kennedy's head were positioned in the drawing. Then the line of sight was drawn between Zapruder and Kennedy's head. Next, the direction angle derived from the laboratory replication was duplicated in order to arrive at the trajectory direction line on the Dealey Plaza map. This line was then extended rearward until it intercepted the face of the first building it encountered—a point approximately 11 feet west of the southeast corner of the Texas School Book Depository. (See fig. II–11.)

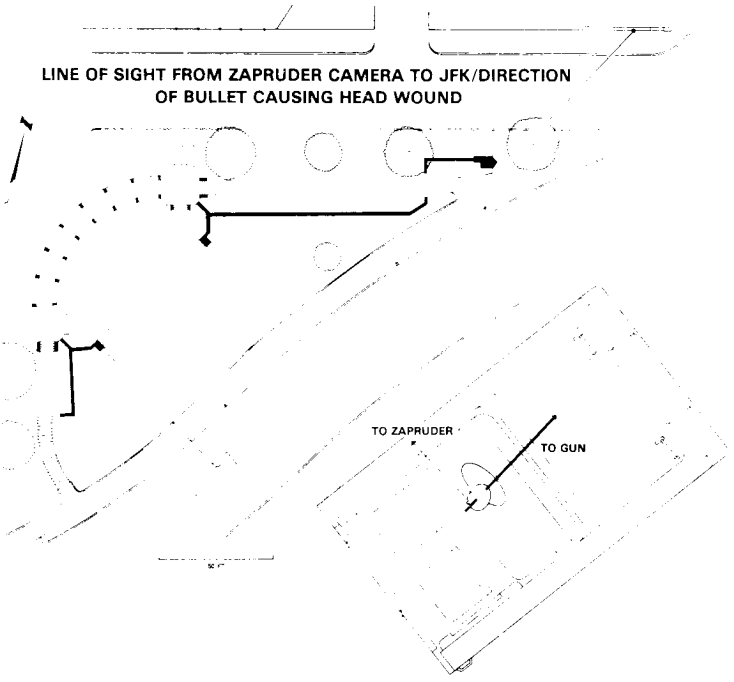

FIGURE II–11.—This diagram depicts the line of sight from Zapruder's camera to President Kennedy and the trajectory direction of the bullet that caused the fatal head wound. Note that the limousine shown at the right is an enlargement of the one drawn in the middle of the diagram.

(139) In order to show the slope of the trajectory without distortion, it was necessary to develop an oblique elevation view shown in fig. II–12. This view is an orthogonal projection onto a vertical plane parallel to the bullet's trajectory. In this view, the resulting trajectory slope of 16° is shown to intersect the Texas School Book Depository at a point approximately 11 feet west of the southeast corner of the building and 15 feet above the sixth floor windowsills.*

* The revision in relative heights of the inshoot and outshoot wounds in Kennedy's head resulted in most of the difference in this trajectory from that presented in testimony before the House Select Committee on Assassinations on September 12, 1978. The remaining revisions resulted from the availability of a superior enhanced reproduction of Zapruder frame 312 for comparison with the calibration photographs.

LINE OF SIGHT FROM ZAPRUDER CAMERA TO JFK/SLOPE OF BULLET CAUSING HEAD WOUND

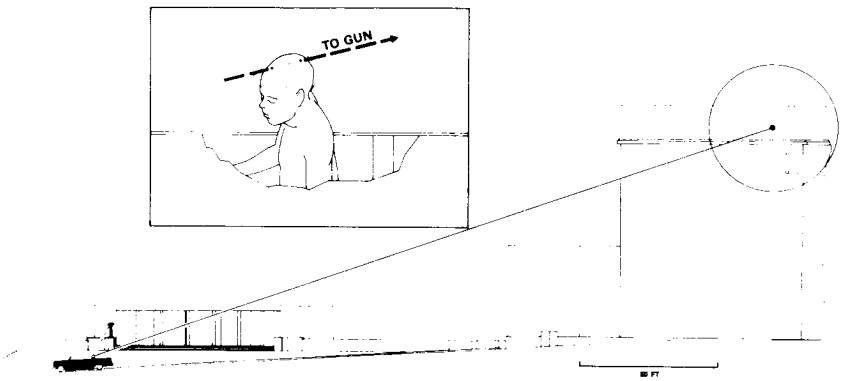

FIGURE II–12

(140) A circle with a radius of 23 feet has been drawn around the intersect point in figure II–12 represents the estimated minimum reasonable margin of error for this trajectory analysis.* To derive this estimate of the margin of error, each step in the analysis was checked for possible errors. Factors such as the position of Zapruder and Kennedy and the height of the pedestal on which Zapruder stood were not considered significant sources of error. The major uncertainties related to the wound positions and the orientation of Kennedy's head relative to Zapruder.

(141) For example, of critical importance in comparing calibration photographs with Zapruder frame 312 was the apparent position of Kennedy's right ear in relation to his nose, brow and back of head. An error of 1.0° (equal to about 0.16 centimeter), in positioning the ear on the replica of the head would yield approximately 1.0° error in the deduced trajectory ** if not offset by other factors in interpreting the photographs or elsewhere. Similarly, establishing the relationship of those elements critical in determining the degree to which Kennedy's head was nodding forward (for example, the line from his brow to his upper lip relative to the slope of the street) also required careful and repetitious measurements to minimize errors. All measurements were made repeatedly, using as many independent image cues as could be found. The redundancy of the cues selected and the repetition of the studies, coupled with the probable random direction of any errors introduced, allows the Panel to conclude that a liberal estimate for the margin of error is about 5° (that is, a 23-foot radius around the intersect point at the Texas School Book Depository).

(2) The back-neck case

(142) According to the autopsy photographs, the first bullet to strike Kennedy entered his back slightly about his shoulder blade and slightly to the right of his backbone. (See fig. II–13.) This bullet passed

*That is to say that the margin of error could be greater.

**A 1-degree error results in a movement of about 4 feet at a range of 250 feet.

through soft tissue hitting no bone, and exited at the front of his neck. (*47*) Independent determinations by the Photographic Evidence Panel showed the entrance wound to be from 4 to 5 centimeters from Kennedy's center plane and the exit wound to be on the center plane or as much as 0.5 centimeters to its left. When seen in the autopsy position, the outshoot wound was described as being at about the same height (or slightly higher) relative to the inshoot wound. The distance between the wounds was determined to be 14 centimeters.

J.F.K. WOUND LOCATIONS

NOTE: DISTANCE BETWEEN INSHOOT & OUTSHOOT WOUNDS = 14cm

FIGURE II–13

(143) Based on the acoustics results (*48*), the camera blur study (*49*) and the visual observations made by the Photographic Evidence Panel, (*50*) it was determined that Kennedy was struck by this bullet at a time corresponding approximately to Zapruder frame 190. Accordingly, to determine Kennedy's orientation at that point, frame 190 and adjoining frames were closely scrutinized. (*51*) (See JFK exhibits JFK F–225–227.)

(144) The best record of Kennedy's posture, torso inclination, and shoulder "hunching" is a photograph taken by Robert Croft at about the time of Zapruder frame 161. (*52*) (See fig. II–14, JFK exhibit F–135.) This correlation was established by the Photographic Evidence Panel by examining features in the Croft photograph and studying Croft's movements as recorded in the Zapruder film.

(145) In Croft's picture, Kennedy and other persons in the limousine are seen from a perspective that permits a reasonable determination of their posture and orientation. Kennedy's upper torso/neck region was inferred from this photograph to have been inclined forward at an approximate angle of 11° to 18° relative to a line drawn upward from and perpendicular to the road surface. The range of this angle is well within a much larger range derived from studies of many other photographs taken during the motorcade. Although the Croft photograph corresponds to Zapruder frame 161, there is no indication in the Zapruder movie that Kennedy changed his inclination substantially before he was hit in the back. (*53*) (See JFK exhibits F–226–242.)

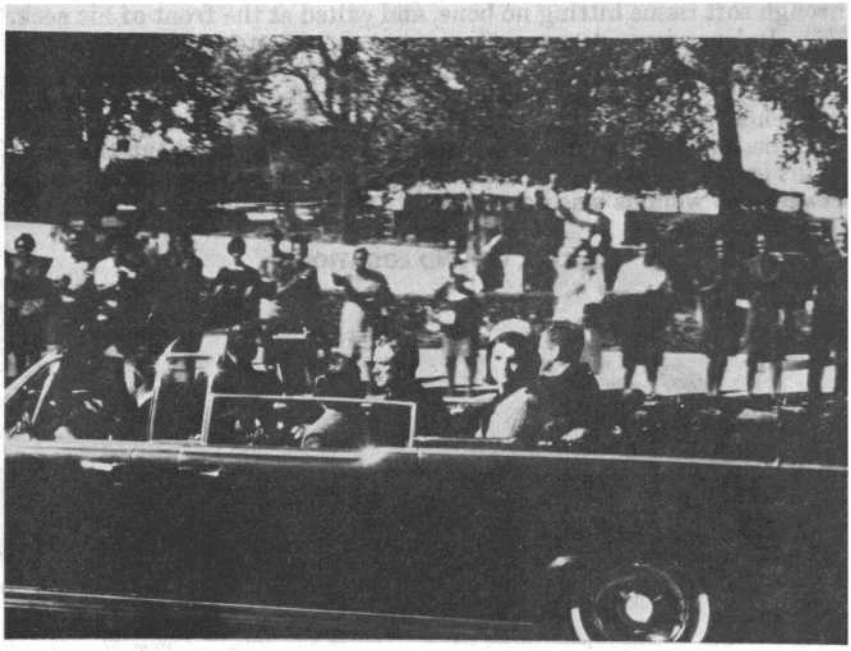

FIGURE II–14

(146) The Croft photograph also shows Kennedy's torso facing nearly straight forward. At Zapruder frame 190, however, he is seen to turn his head about 60° to his right (see JFK exhibit F–226), and it is reasonable to expect that he also would have rotated his shoulders a small amount in the same direction. Most probably, this rotation was only 5° or less, as judged by the absence of obvious large shifts in body position in the Zapruder movie. Thus, it was assumed that, except for turning his head by about 60° and his torso perhaps by 5°, Kennedy made no major changes in posture after frame 161. This assumption is supported by a photograph taken by Phillip Willis at about the time of Zapruder frame 202.* (See fig. II–15, JFK exhibit F–155.)

*Establishing when the Willis photograph was exposed in reference to the Zapruder film was done by the Photographic Evidence Panel by studying the Zapruder film and determining when Willis could actually be seen snapping his picture. In the study of the back/neck wounds trajectory, calibration photographs of the anthropometric dummy were taken but not used (that is, for measurement analysis) because, unlike the head, the torso is quite mobile, and consequently there is no stable relationship between the various body parts. It was decided that to rely on the calibration-photograph technique in this instance would have given a false sense of accuracy to the analysis.

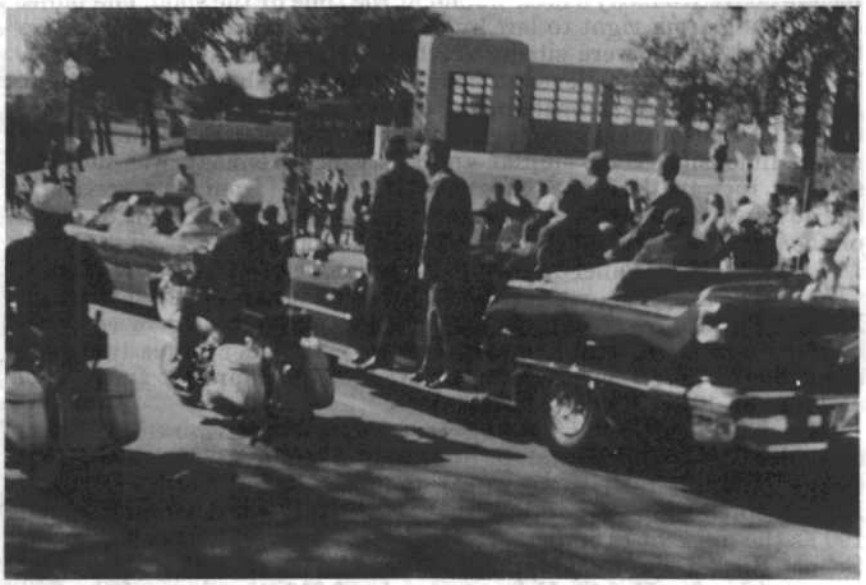

FIGURE II–15

(147) The Panel then had to adjust slightly the wound locations that had been provided based on the autopsy photographs and X-rays because of their difference in body position from that at the time of the shooting. During the autopsy, Kennedy was in an anatomical position with his face tilted as if looking upward about 35°, a posture and conformation significantly different from those at the time of the assassination.

(148) Appropriate adjustments were made under the direction of Dr. Clyde Snow, a forensic anthropologist at the Civil Aeromedical Institute of the FAA's Aeronautical Center. It was determined that returning Kennedy's head to a normal position relative to his body would, according to laboratory tests on men of similar build, adjust his neck wound down about 1.0 centimeter toward his breastbone. Returning Kennedy's head to the position it was in at the time he was first wounded—about 60° to the right of straight ahead of his torso—caused only a slight change in the position (approximately 0.1 centimeter to the right of its observed position in the autopsy photographs). (*54*)

(149) Because the Zapruder film showed that Kennedy had raised his right shoulder slightly so as to place his elbow on the side of the limousine, the resulting movement of skin at the inshoot location was also assessed. It was found that the wound was approximately 0.1 centimeter higher and 0.2 centimeter closer to his midplane than the post mortem photographic observations by themselves indicated. (*55*) While only the vertical position of the neck wound was substantially altered by these changes in conformation, all the adjustments were included in the analysis of trajectory.

(150) Using the average locations and adjustments, the back wound was located at a point 4.4 centimeters to the right of and 1.1 centi-

meters above Kennedy's neck wound at the time of the shot. The bullet was moving from right to left by 18° and downward by 4.0° relative to Kennedy if he were sitting erect (not inclined forward or aft). Since Kennedy was believed to have been turned about 5° to his right relative to the fore-and-aft line of the limousine, it is concluded that the bullet was moving from right to left by 13° relative to the midline of the limousine. By a similar analysis, since Kennedy was inclined slightly forward by approximately 11° to 18° (from true vertical), the downward slope of the trajectory, taking into account the 3° slope of the street, was established at between 18° and 25° (4° plus 11° to 18°, plus 3°). The Panel decided to use an angle of 21° for its analysis.

(151) The analysis by the USGS of the limousine's motion through Dealey Plaza provided both the location and angular orientation of the limousine at a time corresponding to Zapruder frame 193; (*56*) adjustments were then made with reference to Zapruder frame 190. (See fig. II–10, JFK exhibit F–133.)

(152) The direction of the trajectory was then determined by drawing a line on a scaled diagram of Dealey Plaza at a 13° (that is, 18° minus 5°) angle relative to the car and extending it to the rear until it intercepted the first building that it encountered. Assuming frame 190 as the moment of impact, the trajectory line intercepts the Texas School Book Depository approximately 14 feet west of its southeast corner. (See fig. II–16). Using an angle of 21°, the slope of the trajectory was then drawn onto a similarly scaled diagram and found to intersect the Texas School Book Depository at a point almost level with the sixth floor windowsill. (See fig. II–17.)

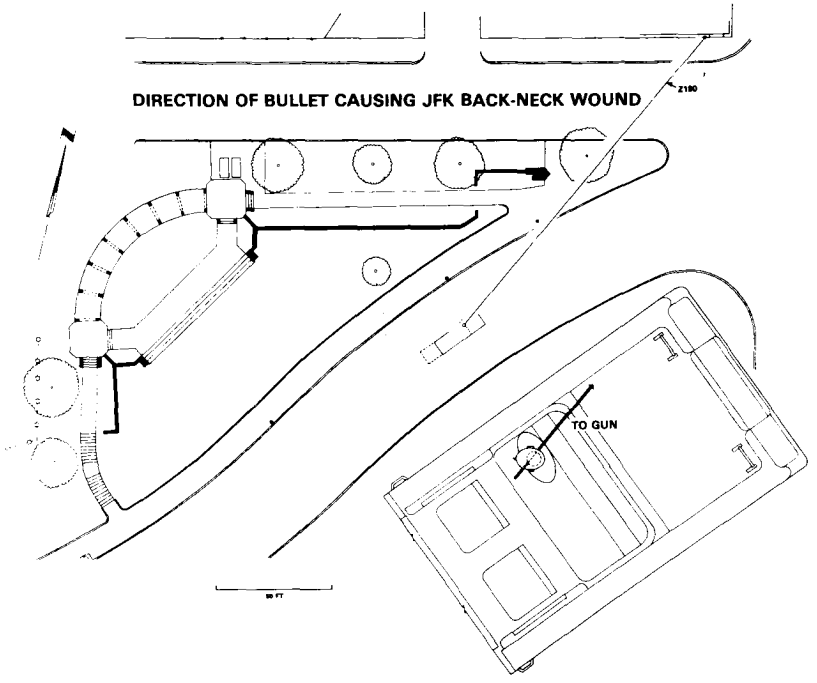

FIGURE II–16

SLOPE OF BULLET CAUSING JFK BACK-NECK WOUND

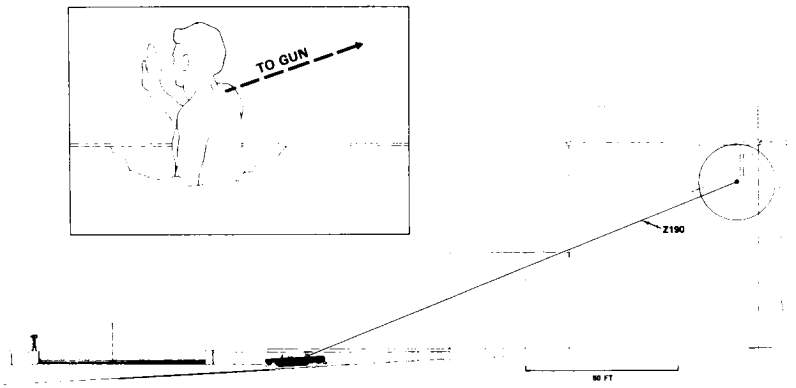

FIGURE II–17

(153) A circle with a radius of 13 feet has been drawn about the intercept point of the trajectory in figure II–16, reflecting the margin of error. It represents the estimated minimum reasonable margin of error that can be ascribed to this analysis.

(154) The same kinds of considerations as were discussed for the head wounds case were applicable in assessing the accuracy of the trajectory based on the President's torso wounds. Here the most critical issue was Kennedy's upper torso attitude rather than the orientation of his head. Consequently, different types of problems were encountered.

(155) The Croft photograph, while quite illustrative of Kennedy's posture, lacked two features noted in Zapruder frame 312. Since the torso is flexible, no clear stable relationship could be established between the photographed exterior and the unseen interior. Further, this picture was taken at least 1.5 seconds before Kennedy was wounded. During this interval, he had turned his head about 60° to his right and may have shifted his torso slightly. Thus, errors of 5° may easily be present in this interpretation. Finally, an accurate determination of his back and neck wound locations was impeded both by the extremely inappropriate lighting and composition of the autopsy photographs and by the distortions resulting from the tracheostomy performed at Parkland Memorial Hospital. These latter problems probably contributed little to the uncertainty in trajectory location as compared with the more serious difficulties arising from the poor photographic definition of his posture and position.*

(3) The single-bullet theory trajectory

(156) In order to examine the hypothesis that the bullet responsible for Kennedy's back and neck wounds was also responsible for Connally's wounds, a trajectory was constructed based on Kennedy's exit

*The 5° margin of error resulted in a smaller margin-of-error radius than in the head wound trajectory because in this case the limousine was substantially closer to the Texas School Book Depository. (See fig. II–10, JFK exhibit F–133.)

neck wound and the entrance wound in Connally's back. The hypothesis was to be evaluated by determining whether this trajectory lay close enough to the back-neck trajectory to make it reasonable to conclude that both are consistent with the trajectory of one bullet. Necessarily, the margin of error radius for the Kennedy-Connally trajectory would have to intersect the depository at a point within the 13-foot-radius circle of probable accuracy for the back-neck wound trajectory established earlier. Ideally, of course, the two trajectories would line up precisely, but this standard was considered unrealistically high, because, as with Kennedy, Connally's position at the time of this shot could not be precisely established; moreover, each trajectory was subject to its own sources of error.

(157) In addition to the information that already had been analyzed concerning Kennedy's neck wound, derivation of this trajectory required placement of the location of Connally's entry wound to the back. At the committee's request, Connally agreed to have the position of his back wound redetermined by the Forensic Pathology Panel. His inshoot wound was described as being immediately above his right armpit. This description is essentially consistent with figure II–18. (JFK exhibit F–399.) (*57*)

LOCATION OF INSHOOT WOUND IN BACK OF GOV. CONNALLY

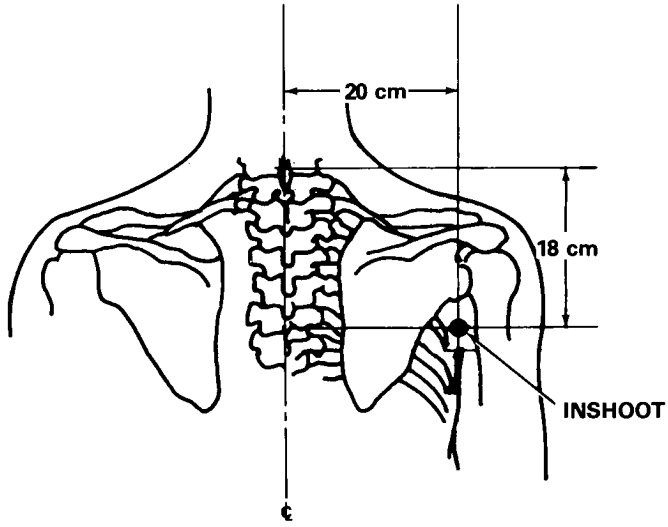

FIGURE II–18

(158) In contrast to the analyses involving Kennedy's wound pairs, the two-man wound combination required focusing on the positions of the two men relative to each other and to their surroundings in Dealey Plaza, rather than just on individual details of posture and orienta-

tion. This analysis was accomplished by reviewing Zapruder frames 180–207, the Croft photograph, and photographs taken by Hugh Betzner and Phillip Willis, two witnesses who were both standing behind and to the left of the Presidential limousine.

(159) Two independent determinations of the lateral relationship between the two men were made. The first consisted of a photogrammetric analysis of several pairs of pictures taken from the Zapruder movie between frames 182 and 200. These pairs were viewed together in a stereoscopic viewer so that together the pairs would project a single, three-dimensional image that could be evaluated for the relative depths of the objects that they portrayed.* The stereo pairs clearly showed that Kennedy was seated close to the right-hand, inside surface of the car, with his arm resting atop the side of the car and his elbow extending, at times, beyond the body of the car. Connally, on the other hand, was seated well within the car on the jump seat ahead of Kennedy; a gap of slightly less than 15 centimeters separated this seat from the car door. (See fig. II–19.) (*58*)

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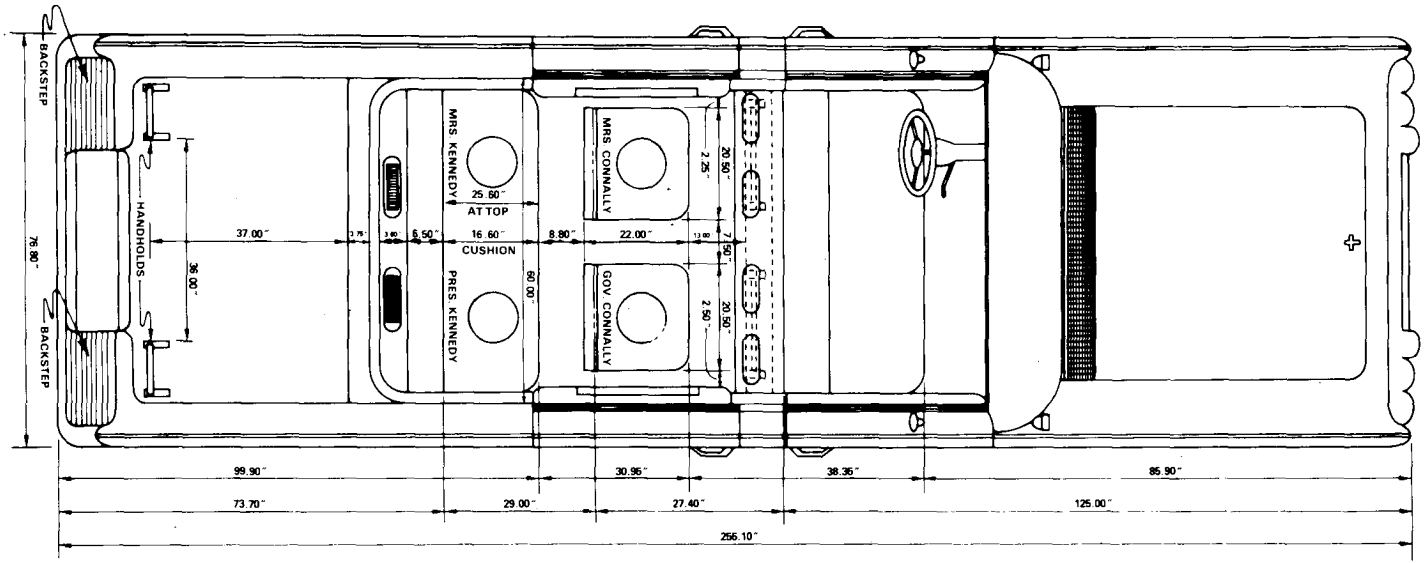
*A similar stereophotogrammetric analysis, performed by the Itek Corp. and verified by the photographic evidence panel, indicated that in several stereo pairs Connally was sitting 10.2 to 20.3 centimeters to the left of a line extending straight forward from Kennedy. (See *John Kennedy Assassination Film Analysis*, Itek Corp. (1976), pp. 43–48).



PRESIDENTIAL LIMOUSINE (November 22, 1963)

1961 Lincoln Continental — Modified

Dimensioned from original body draft by
Hess & Eisenhardt Co. of Cincinnati, Ohio

Scale ¾″ = 1′-0″

FIGURE II–19

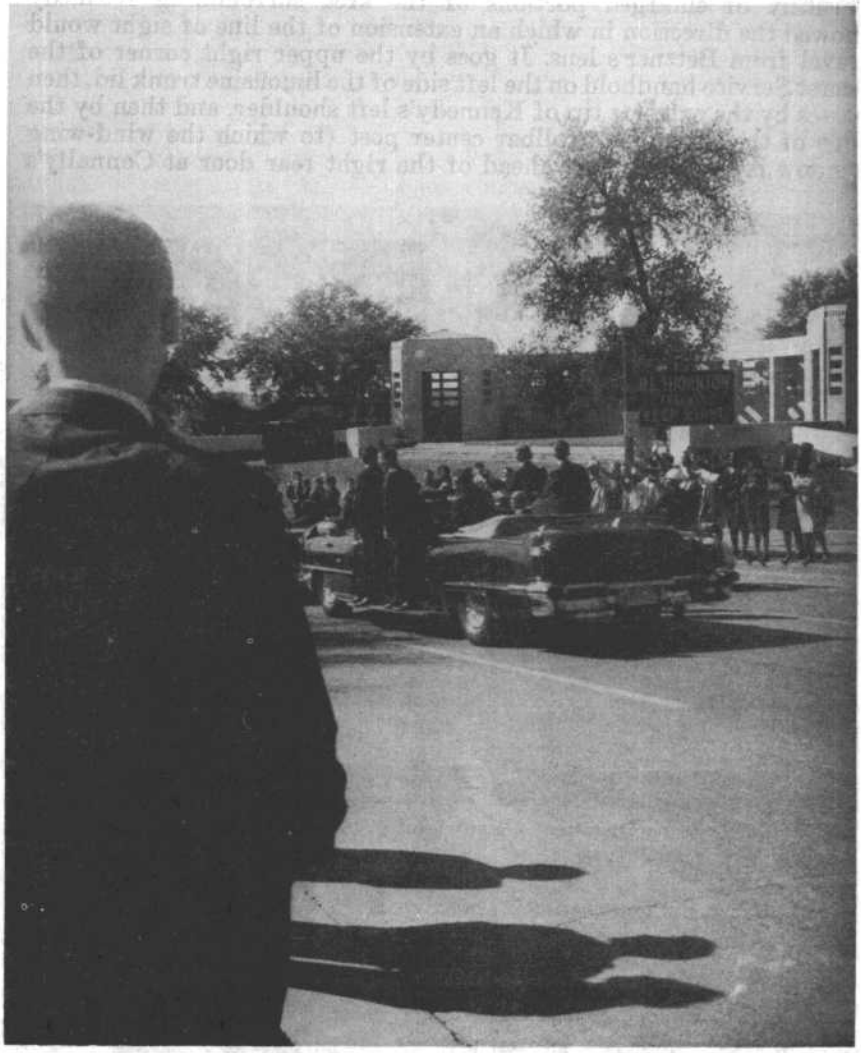


FIGURE II–20

(160) The second photographic analysis, which was based primarily on the Betzner and Croft photographs, confirmed these observations. The Betzner photograph (see fig. II–20) was determined by the panel to have been taken at the time Zapruder frame 186 was exposed.*

*A first generation print of a photograph taken by Hugh Betzner, very close in time and from a similar vantage point as the Willis No. 5 photograph, was examined by the panel; no enhancement processing was performed as the original negative was never located. The Betzner photograph was correlated to the corresponding Zapruder frame by establishing when a Secret Service agent riding in the car behind Kennedy could be seen in both Zapruder's and Betzner's immediate line of sight.

Scrutiny of enlarged portions of the area surrounding Kennedy showed the direction in which an extension of the line of sight would travel from Betzner's lens. It goes by the upper right corner of the Secret Service handhold on the left side of the limousine trunk lid, then passes by the extreme tip of Kennedy's left shoulder, and then by the edge of the limousine's rollbar center post (to which the wind-wing window is attached) just ahead of the right rear door at Connally's

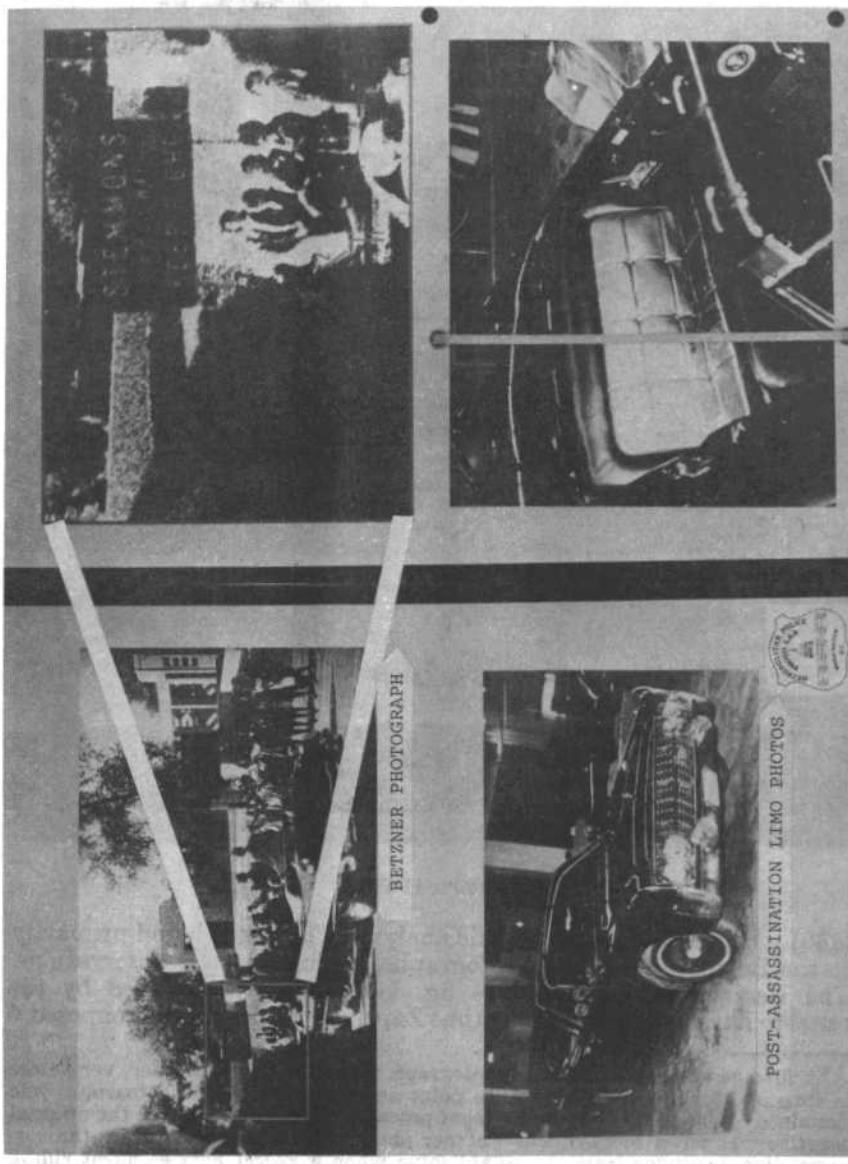


FIGURE II–21

FIGURE II–22

right.** This line establishes a boundary to the left of which no part of Kennedy can be seen. Nor are there visible signs of Connally's right shoulder or arm slightly to the left of this boundary (the line of sight is limited by the spectator's arm in the foreground). Therefore, Connally must be seated to the left of this line of sight.

(161) With these two observations and some supportive evidence drawn from the remaining pictorial evidence, it was possible to outline Kennedy as he would have been seen from directly above. The key additional features used were his posture and inclination, which were derived from the Croft picture (see fig. II–14), and the slight indication of torso rotation to his right, derived from the Zapruder film. Next, a similar outline was drawn for Connally, with his shoulders against the backrest of the jump seat as far to the right as can be justified in view of the Betzner photograph, and turned to his right.

(162) The direction in which Connally's torso was facing has been determined on the basis of viewing the Zapruder movie and by care-

**Fig. II–21 (JFK exhibit F–136) demonstrates the Betzner photograph line-of-sight analysis. The rollbar center post has a diagonal appearance in the Betzner photograph because it is inclined inward from the side of the car toward the rollbar. See fig. II–22 for a clearer view of the rollbar post, as seen from a similar angle in a photograph taken by James Altgens on Houston St. less than a minute earlier.

ful study of a particularly clear stereo pair taken from the movie. The estimates of the angle of his twist vary from 30° to slightly over 45°. The two outlines show the positions of the men relative to one another. (See fig. II–23.) Connally cannot have been sitting very far to the left of this position in view of his location in Zapruder frame 190. (See JFK exhibit F–226.)

RELATIVE POSITIONS OF PRESIDENT KENNEDY AND GOVERNOR CONNALLY AS DEDUCED FROM PHOTOGRAPHIC EVIDENCE

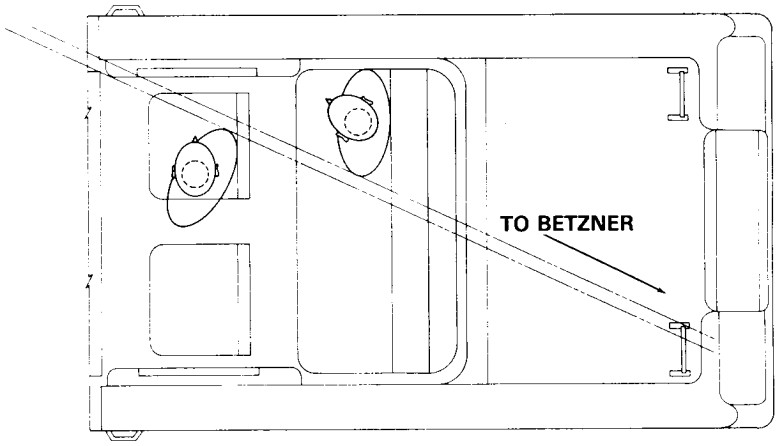


FIGURE II–23

(163) The point-to-point distance between Kennedy's neck and the part of Connally's back that was wounded was determined photogrammetrically in the Croft photograph to be approximately 60 centimeters. The height differential between the two was determined in a similar manner to be 8 centimeters.*

(164) Using the lateral and longitudinal relationships, given the limousine as the frame of reference (see fig. II–23), the direction in which the bullet was found to have been moving from the rear was 12.7° from right to left relative to the midplane of the car. The direction of the trajectory was thereby determined by drawing a line at a 12.7° angle relative to the car and extending it to the rear until it intersected the first building that it encountered—the Book Depository, at a point approximately 2 feet to the west of the southeast corner of the building, using Zapruder frame 190 for the moment of impact. (See fig. II–24.)

*The appearance of an even greater height difference between the two men, as depicted in the Croft photograph, resulted from the more inward position of Connally in the car and the slightly downward line of sight from Croft's camera.

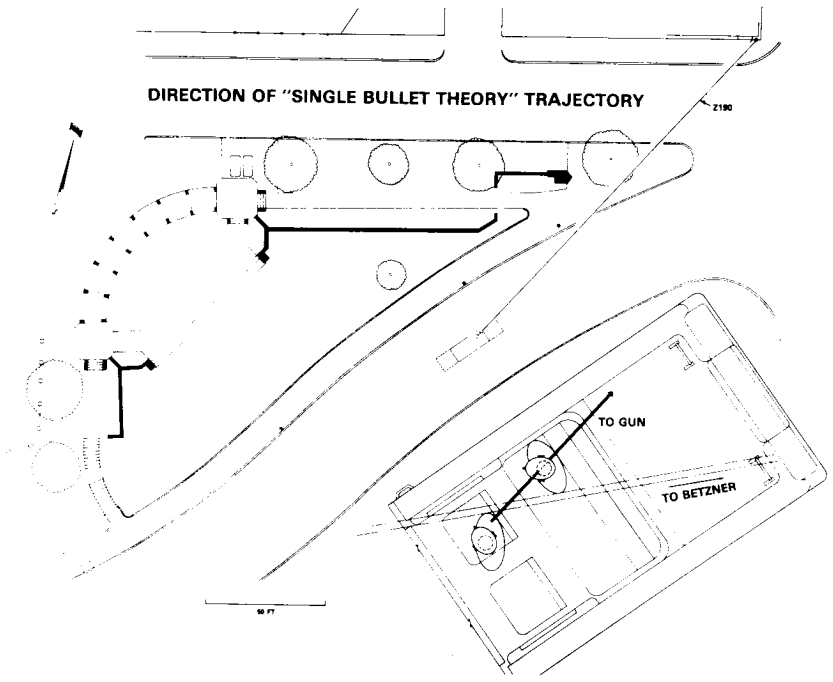


FIGURE II–24

(165) In deriving the slope of the trajectory, the difference in height between the two wounds, the 60-centimeter distance between them, and the inclination of Elm Street, were taken into account. Kennedy's neck wound was 1.1 centimeters below his first thoracic vertebra; his forward inclination lowered the wound an additional 2.4 centimeters. Connally's inshoot wound was 18 centimeters below his first thoracic vertebra. Thus, if the men had been sitting so that the tops of their heads were at equal heights, Kennedy's wound would have been 14.5 centimeters higher than Connally's.* Then, taking into account that Kennedy was seated approximately 8 centimeters higher than Connally (as observed in the Croft photograph), Kennedy's wound is found to have been 22.5 centimeters higher (14.5 plus 8 centimeters) than Connally's relative to the car. This height difference over a distance of 60 centimeters (point-to-point distance between the wounds) yields a downward slope of about 22° from Kennedy's wound to Connally's. Finally, accounting for the 3° slope of the street, the slope of the trajectory is found to be 25°.

(166) This means that the bullet was traveling at an angle of 25° below true horizontal as it passed forward from Kennedy's neck to Connally's back.** Using the position of the men at the time of Zapru-

*This analysis makes the assumption that the distance in each man from the top of his head to his first thoracic vertebra is approximately the same.

**This slope is 2° steeper than described in testimony before the committee on September 12, 1978, because the former was based on a 6-centimeter height difference instead of 8 centimeters, as presently interpreted.

der 190, if this line is extended toward the rear, it intercepts the depository building about 9 feet above the sixth floor windowsill.* (See fig. II–25.)

SLOPE OF "SINGLE BULLET THEORY" TRAJECTORY

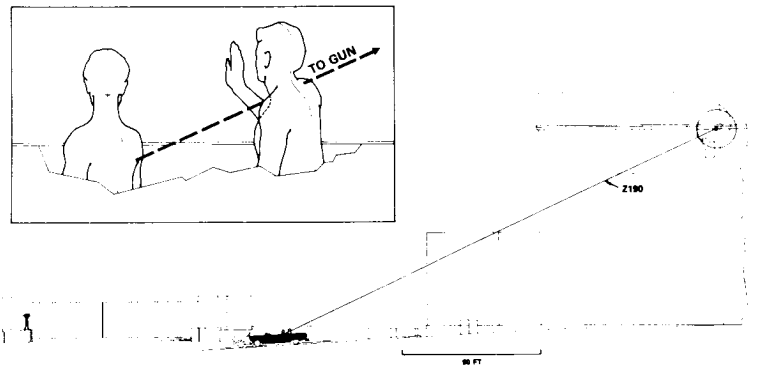


FIGURE II–25

(167) In figure II–25, a circle of 7 feet radius, representing the estimated minimum reasonable margin of error, has been drawn around the intercept point. It is smaller than those of the other two trajectories simply because the distance between the two wounds (60 centimeters) is more than four times as great as that for the back/neck case (14 centimeters) and five times that for the fatal bullet (11 centimeters). This longer baseline distance admits greater error in wound location and body position, while yielding superior accuracy. The eastern border of the error circle is somewhat better fixed than the western because the right-most position of Connally was better defined than the left-most.

(168) The consistency of the single-bullet theory trajectory with the back/neck shot trajectory described earlier is illustrated by their similar direction and slope. Note that the intercept point of the single-bullet theory trajectory at the Texas School Book Depository lies very close to the margin of error circle established for the back-neck case. Indeed, the two error circles overlap substantially. (See figs. II–17 and II–25.) Clearly, this analysis supports the single-bullet theory. The reliability of this trajectory in indicating the position of the gunman would be less if it could be shown that the bullet had been deflected as it passed through Kennedy's tissue. Nevertheless, the evidence indicates that the bullet passed near, but did not strike, the right lateral processes of the seventh cervical and first thoracic vertebrae (nor any other bony matter). (*59*) Consequently, the deflection, if any, was probably negligible.

*This result differs somewhat from the testimony given before the committee on September 12, 1978, because the adjustment in the height differential between the two men affected the ultimate determination of trajectory slope.

ADDENDUM A

Calibration Photographs of the Replica of President Kennedy's Head

(169) Photographs of Kennedy taken immediately before each shot provide invaluable, albeit imperfect, records of his position and orientation at the time of the assassination. The quantitative interpretation of these photographs was facilitated through detailed comparisons with calibration photographs taken of a full-scale replica of Kennedy's head, upper torso, and arms.

(170) Calibration photographs may be defined as photographs of a replica that is geometrically and texturally representative of a subject; they are taken under controlled conditions and are used to facilitate quantitative interpretation of photographs of the real subject that were taken under uncontrolled circumstances. Requirements for a good calibration photograph include: accuracy of the replica, photographic distortion similar to that in the real-life photograph under study; comparable positions for the camera and replica; and comparable lighting distribution. The calibration pictures should have somewhat superior photographic qualities in terms of spatial resolution and contrast so that error will not be introduced into the interpretation.

Head replica

(171) To maximize the accuracy of the replica, the Aeromedical Research Institute of the FAA's Aeronautical Center worked with a group of high-quality photographs from the National Archives. Using dimensions obtained from well characterized X-rays of Kennedy's head taken shortly before the assassination, the size and proportions of his skull and the thickness of overlying tisue (front and rear) were established. Modeling clay was applied to a standard plaster skull until the form of his head was duplicated in many aspects. To achieve improved photographic realism, artificial eyes and a wig were added. The head was then mounted on the neck of a standard FAA anthropometric dummy.

Simulation of lighting and environment

(172) A single studio light was used to simulate the Sun, with two small studio floodlamps to augment the illumination by the studio skylight of the figure and the neutral background. At the time of the first shot, Kennedy had been facing west. The spotlight was accordingly positioned to the model's left. It was placed about 36° above horizontal from the head, a position comparable to that of the midday November Sun. Similar lighting was arranged for the head-wound shot. In this case the elevation of the spotlight (Sun) was about 56°, compensating for the erect placement of the head on the dummy, and it was placed nearly straight in front because Kennedy had been facing south.

(173) Camera stations—the various points from which the dummy would be photographed—were marked out on the studio floor in an arc 25 feet from the bridge of the model's nose. Two plumb bobs were suspended beside the figure to provide a precise vertical and angular reference respectively. Beads were installed on each plumbline at a point level with the bridge of the dummy's nose. The elevation of the camera was varied to achieve the desired angles of elevation relative

to the dummy. (This caused the actual distance between the camera and the dummy to change slightly.)

(174) Once the camera stations were established, a series of photographs was taken at varying elevations from each station, with the location of each photograph recorded. The pictures were then compared with an enhanced photograph of Zapruder 312. (See fig. II–8.) The goal was to determine the angular orientation of Kennedy's head relative to his surroundings in Dealey Plaza. Since the positions of the Zapruder and Nix cameras, with which the best pictures had been taken, were known, only the position angles relative to each camera's line of sight and to vertical references visible in the respective pictures had to be found.

(175) The relative positions of the features of Kennedy's head varied with the viewing aspect. In Zapruder frame 312, part of Kennedy's nose was obscured by his right cheek because his head was turned slightly away from the camera. His right ear appears slightly forward of where it would have been had he not been facing slightly away. His cheekbone and ear appear slightly elevated in Zapruder frame 312 as the camera was, in effect, viewing the President from slightly "below" because of the inclination of his head to the left.

(176) All these relationships among features were accounted for simultaneously during comparison with the calibration photographs. Serious impediments to accurate interpretation of the photograph were occasioned by the extremely complicated background to the President's face resulting from Mrs. Kennedy's pink suit and dark blue blouse and by the interior surface of the left side of the limousine. These problems were overcome in part by the use of a computer-enhanced version of Zapruder frame 312. (See fig. II–8.)

ADDENDUM B

Correlating Trajectory to the Acoustics Results: Trajectory of Head-Shot Wounds Based on Zapruder Frame 327

(177) The acoustics analysis indicates that four shots were fired at the Presidential limousine with the first, second, and fourth shots coming from the Texas School Book Depository and the third from the grassy knoll. (*60*) Given these findings, as well as the timing of the shots, approximately 1.6, 6, and 0.7 seconds apart, Zapruder frame 312, which immediately precedes the frame that shows the fatal head shot, theoretically could be the time of impact of either the third or fourth shot of this sequence. (*61*)* If it was the fourth shot, the third shot would have had to impact (if it had hit) approximately at Zapruder frame 296; (*62*) if it was the third, then the fourth shot would have had to impact (if it had hit) approximately at Zapruder frame 327. (*63*)** (See illustration 33a, fig. II–26.)

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*The first two shots are spaced only 1.6 seconds apart. Consequently neither of these shots could have caused Kennedy's fatal head wound, since it is apparent that at least by Zapruder frame 224, Kennedy and Connally are already reacting to their earlier wounds.

**The correlation between the acoustics tape and the Zapruder film indicate that this shot would have occurred approximately at Zapruder frames 328–329. *See* pars. 108–109 *supra*.

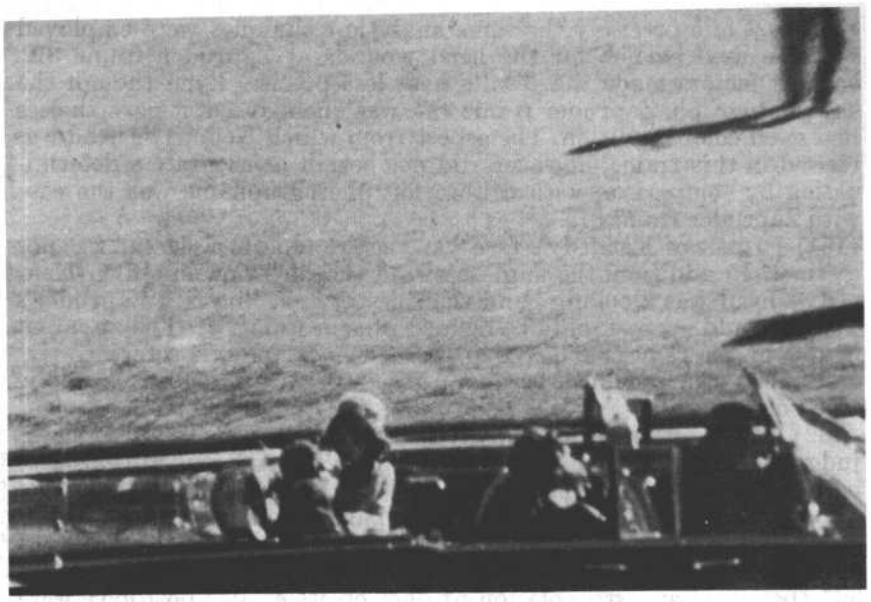

FIGURE II-26

(178) The acoustics, medical, ballistics, and neutron activation analyses, taken together, establish that a shot from the Texas School Book Depository struck the President's head. (*64*) The head shot trajectory analysis based on Kennedy's orientation and location at Zapruder frame 312 assuming this to be the fourth shot fired is consistent with this. Nevertheless, the committee decided to examine the possibility that the fourth shot fired from the Texas School Book Depository impacted at Zapruder frame 327 and that the third shot, fired from the grassy knoll, was therefore responsible for destroying Kennedy's head at frames 312–313.

(179) A trajectory analysis was undertaken based on Kennedy's orientation and location at Zapruder frame 327.* If the trajectory were found to go back to the alleged sniper's window in the Texas School Book Depository, it would not necessarily resolve the question. On the other hand, if it did not go back to that location, the conclusion could be drawn that frame 312 was, in fact, the fatal fourth shot which struck Kennedy's head. This conclusion would have to be drawn because the medical, ballistics, and neutron activation analyses, taken together, indicate that the bullet which struck Kennedy's head was fired from the Texas School Book Depository. If the trajectory analysis indicates that this particular bullet could not have impacted at Zapruder frame 327, then the shot must have occurred at Zapruder frame 312, as the trajectory analysis for that frame (described above) does point in the vicinity of the sixth floor window.

*At the time that this trajectory analysis was undertaken, the preliminary correlation of the fourth shot (based on a third shot at approximately frame 312) was at Zapruder frame 327. Frame 327 was exposed less than 1/18 of a second before frame 328. Kennedy's position did not change noticeably during this interval. Therefore, any difference in resulting trajectory would not be significant.

42-370 O - 79 - 5

(180) While precisely the same analytic techniques were employed as those used earlier for the head wounds at Zapruder frame 312, various factors made the results here less precise. Even though the key photograph, Zapruder frame 327, was unenhanced, it nevertheless had good color rendition. The aspect from which Kennedy's head was viewed in this frame, however, did not permit as accurate a determination by comparison with calibration photographs as was the case with Zapruder frame 312.

(181) Little of Kennedy's face was visible, and his right ear was not distinct. In addition, the angle between the direction in which Kennedy's head was "looking" and the line between him and Zapruder's camera could, at best, only be defined plus or minus 5°. The apparent height of the camera relative to Kennedy's facial axis reference was even more poorly defined because of the absence of good visual reference points.

(182) Best estimates of these two angles, as well as an educated judgment of the degree to which Kennedy's facial axis appeared to be tilted left or right relative to level in the Zapruder frame, were achieved after careful study and comparison of calibration photographs approximating Zapruder frame 327. These angular relationships, plus the position estimated for the limousine at Zapruder frame 327 (based on an extrapolation of data on its earlier position) were then used to orient Kennedy's head relative to the surroundings in Dealey Plaza. Completing the analysis required construction of the line through the wound locations as before and extending the line toward the rear. When plotted, the line intercepts the face of the Texas School Book Depository about three-fourths of the building's length to the west of the southeast corner. (See fig. II–27.) When the slope of the line is derived as before, the line then intercepts the building's vertical plane just above the roof of the building. (See fig. II–28.)

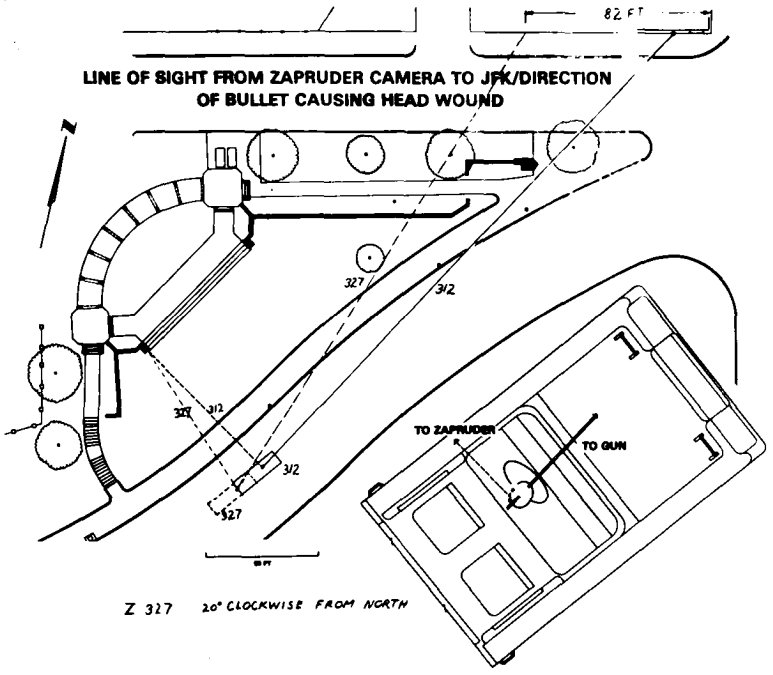

FIGURE II–27

LINE OF SIGHT FROM ZAPRUDER CAMERA TO JFK/SLOPE
OF BULLET CAUSING HEAD WOUND

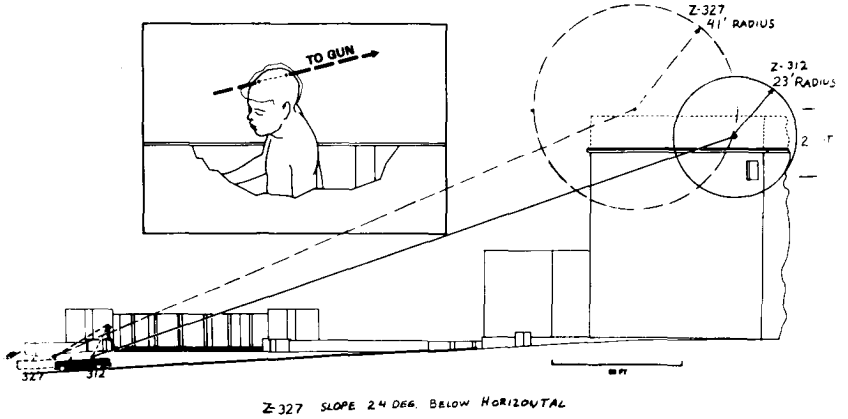

FIGURE II–28

(183) A step-by-step examination of potential errors suggests that this trajectory is subject to approximately twice the error estimated for the head shot trajectory for Zapruder frame 312 because the photographic aspect was so much more difficult and the photographic quality slightly inferior in frame 327.

(184) Despite the problems, this analysis was sufficiently precise to establish that the firing point for a Zapruder frame 327 head shot trajectory is highly inconsistent with either that of the Kennedy back-neck or the single bullet theory trajectories. The latter two are quite consistent with an origin in the southeast sixth floor window of the Texas School Book Depository, whereas, even with a 46-foot estimated minimum reasonable margin of error radius, the head trajectory for Zapruder frame 327 does not take in the alleged sniper's window. For this reason, it is highly unlikely that the head wounds were inflicted by firing a bullet from the southeast window that impacted at the time of Zapruder frame 327.

(185) Once Zapruder frame 327 has been eliminated as a possible fourth shot fired from this window, the conclusion must be made that this fourth shot must have occurred at Zapruder frame 312.

5. PHOTOGRAPHIC EVIDENCE OF DEALEY PLAZA

[See pars. 241–346 infra.]