

PHYSICS OF THE MOTION
OF THE RIFLE SHOT IN THE
ASSASSINATION OF PRESIDENT KENNEDY

backwards recoil of President
the effect of a single shot
shooting at taped melons
seats driven away from the rifle
direction. We analyse previous
under film by critics and
the failure of the Warren

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are listed here is meant to indicate
content is the work of P.L.H. The
tests of a hypothesis by L.W.A., in which

of the report to you for your critical comments.
to submit a brief article on the physics of the problem to
journal for physicists. We expect to distribute
report to students of the Warren Report after
your comments have been considered, and after the short version
that the Physics Today article will be picked up by
the press. We consider this material strictly confidential at this time.

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central in the controversy over the Report of the Warren Commission on the assassination of President Kennedy has been the question of the number and direction of the shots fired. If shots came from two different directions, there must have been a conspiracy. Critics of the Warren Report have drawn arguments against the Commission's conclusions from the principal physical record of the assassination, a 25-second color film taken by amateur photographer Abraham Zapruder.

The most detailed study yet published of this and other photographs of the assassination is Six Seconds in Dallas, by Haverford philosophy professor Donald Thompson (Bernard Geis, 1967). Thompson analyzed in detail the one part of the Zapruder film which appears most strikingly to contradict the Commission's conclusion that all of the shots were fired from behind and above the President. Kennedy is obviously driven backward and to the left by the shot which strikes him in the head, producing a massive and fatal wound. As we will discuss below, the Warren Commission ignored this evidence, but several critics have claimed that the backward motion is in itself evidence of a shot from the right front (the direction of the "grassy knoll"). Thompson measured the motion of the President's head, and noted a forward acceleration followed almost immediately by a comparably large backward acceleration, leading to the backwards motion which is visible over several frames of the film. This, Thompson concluded, was evidence that two different shots had struck the President at about the same time - one from the rear, and another from the front.

Despite the inherent implausibility of two shots striking the President within a tenth of a second of each other, it was not at all obvious that the backward motion could be consistent with a shot from any direction except the front. Thompson considered and rejected the most obvious alternative explanations: that Kennedy's head struck some surface and bounced back, that Mrs. Kennedy pulled

her husband over, that the car struck him, or that the car struck him from the rear, or that the car struck him from the side. He invoked Newton's law of conservation of momentum to conclude that the car could not have been involved in a shot from the front. On this point, Thompson quoted Dr. A. J. Riddle, a U.S. physicist and neurologist:

Basically the law says that if a subject hit by a projectile will be given a motion that has the same direction as that of the projectile. At a shooting gallery, for instance, the ducks fall away from the marksmen, not toward him. This, if someone is shot, and the shot strikes him, the general direction of recoil will be away from - not toward - the marksmen. (Page 91, emphasis added)

I know of Dr. Alvarez's interest in the Warren Report from his analysis of the Zapruder film in 1967. He had found evidence that Zapruder had jiggled his camera, probably in reaction to a shot, at a point before the Commission thought the first shot had been fired. (Alvarez communicated these observations to friends of his at CMI; they were prominently featured in the "CMI Report", a four-hour program presented in the summer of 1967.) He had agreed that CMI had not adequately handled the question of the backward motion after the fatal shot, and I told Alvarez of the detailed study of this point in Thompson's book.

After reading Thompson's work, Alvarez pointed out to me that the fast backward motion might be just what he would expect from a single shot from the rear, under certain circumstances. As Dr. Riddle undoubtedly realized, conservation of momentum has simple and easily predictable consequences only for collisions of rigid or nearly rigid bodies. (Riddle did qualify the conclusion quoted above by referring to the "general direction" of the recoil, but this qualification was not included in the original text.) A human, however, is not a rigid body and is not a nearly rigid body. A human, therefore, will not recoil in the same way as a rigid body. He will recoil in the same way as a rigid body only if he is struck in the one or two frames after impact, primarily in the forward direction. Alvarez suggested that the incoming kinetic

energy of the bullet could be made available to drive enough material forward, fast enough, so that its forward momentum was greater than the forward momentum carried in by the bullet; if this were the case, the law of conservation of momentum would require the remaining part of the head to recoil backwards - toward the gun.

When Alvarez saw Thompson's quantitative analysis and graphs of the "retrograde" motion, he realized for the first time that he had to treat the "retrograde motion" seriously. With some simple "back of the envelope" calculations (using a one-dimensional model for the collision) he quickly showed that the observed motion could easily be made consistent with conservation of momentum and energy.

A 160-grain bullet traveling at 1800 feet per second carries about 40 foot-pounds per second of momentum. (These numbers correspond roughly to those for the bullet allegedly used in the assassination, but for this semi-quantitative argument approximate values are sufficient. See Appendix 1 for more details.) Thompson measured the backwards velocity of Kennedy's head after the shot to be about 1.6 feet per second. Estimating the weight of the recoiling part of the head and body at 20 pounds (that is, recoil momentum = 32 foot-pounds per second), we see that Newton's laws (conservation of momentum) require that $40 + 32 = 72$ foot-pounds per second of momentum be carried forward by the fragments of bone, metal, and tissue which are driven forward. (For example, 1 pound of matter going at about 70 feet per second would suffice.) It is probably not possible to estimate accurately the amount and speed of the forward-going fragments, but it does not seem inconsistent with the Zapruder film and other evidence for them to be carrying about 70 foot-pounds per second of momentum forward. Since the bullet mass (weight) is so small compared to the mass of the target or the fragments, there is no difficulty in reconciling this hypothesis with the law of energy conservation -- most of the incident kinetic energy (energy of motion) can be dissipated as heat, with plenty left over to produce the observed "rocket

motor" effect. (In a rigid body collision where the bullet is stopped in the target, almost all of the incident kinetic energy would be lost as heat.)

Just because a hypothesis is consistent with momentum and energy conservation does not mean it is physically possible. Some dynamical mechanism is needed to explain how there can be zero momentum in the direction of the bullet after it has interacted with the target than before. (Once this is understood, it is clear that the part of the target which is not driven forward must recoil back.) This is not as unlikely as it may at first seem. All that is required is that the bullet, as it is slowed down, pulls material from the target along with it, at speeds up to that of the bullet.

We felt that no such hypothesis could be taken too seriously unless it was experimentally verifiable, especially since it violated our intuitive notions. Alvarez asked Sharon (Buck) Buckingham, an expert with guns (who, along with Alvarez and me, works at the University of California Lawrence Radiation Lab) to set up an experiment to test this theory. Buckingham thought it seemed unlikely to work, but agreed to try. The range-master at the San Leandro rifle range was just as skeptical, but generously arranged for us to use the range. Buckingham shot at eight targets of various kinds, and reported that Alvarez' hypothesis did seem to work. We decided that photographs were essential, and returned to the rifle range some months later with a full experimental team. (In addition to Dr. Alvarez and Buck Buckingham, the team consisted of Dewey Machinelli as marksman, and Don Olson and myself as photographers and "consultants" on the Warren Report.) We set up a remote-controlled 8-mm. movie camera and recorded the impact of a bullet on several water- and gelatin-filled containers. We found that the results were inconclusive with such targets, and that melons (as had been used in Buckingham's first tests) were the best for simulating what we thought we saw in the Zapruder film. After the melon season opened, we went to San Leandro a third time.

Warren Commission, with frames 314 and 315 interchanged; some were published in color in the October 2, 1964 issue of Life.)

The results shown in Figure 1 are not just a fluke; in six of the seven tests we filmed using taped melons, we observed recoil toward the gun. The part of the melon that recoiled typically consisted of the taped shell, with distinct entry and exit holes up to a few inches in size, and perhaps one-half to two-thirds of the interior. (We should have weighed the part of the melon that recoiled, but neglected to do so.) Photographs showing more details of our results are presented in Appendices 2 and 3.

Although taped melons consistently showed the "rocket" effect, different kinds of targets reacted differently. An untaped melon would typically shatter explosively; the tape was necessary to hold the hard shell of the melon together (reasonably well simulating, we feel, the tensile strength of a skull covered with skin.) Before melons were in season, we shot at toy rubber balls filled with gelatin. Such targets showed little jettling, and they tended to go away from the rifle. (Apparently the gelatin was more cohesive than the interior of the melon, and the rubber "shell" presumably tended to stretch rather than to fragment.)

In none of our tests with taped melons did we see any forward motion before the recoil. We suggest that the time that elapses before the recoil starts might depend on the details of the structure of the target; the strength of the shell, the viscosity and speed of sound in the interior, etc. That is, under certain circumstances the target would act like a rigid body for a short time and go forward, before the "rocket" effect takes over. There are some questions in my mind about the evidence that Thompson presents for a forward acceleration - i.e., the forward motion between frames 312 and 313 of the Zapruder film. (The raw data (page 27) SIX Seconds in Dallas) shows a large fluctuation in the slowly-varying apparent length of a fixed line, AB, at frame 312. This was

We found that we could quite consistently produce the "unexpected" result, a backwards recoil. Figure 1 shows clearly the effect we were looking for.

The target is a 3-pound hamper melon, well wrapped with 1-inch Scotch filament tape. A .30.06 rifle fired a 150-grain round-nose reloaded bullet

from a prone position about 35 yards to the right; the film was taken at 24 frames per second from a position perpendicular to the line of flight of the bullet. (The target was placed a couple of feet above ground level so that there would be no possibility that it would somehow bounce back after being driven downward by the bullet.) In the first frame after impact (labeled

1), a fine spray of material from inside the melon can be seen jettling out of the exit hole. In the next frame, the jet is bigger, and the rest of the melon is recoiling back. As the spray rather quickly dissipates, the melon continues backwards and, of course, starts to fall down under the influence of gravity. When these frames are projected at normal speed, the recoil dominates and produces a great deal of ambiguity about the "apparent" direction of the shot.

It is of interest to note that the recoil velocity in Figure 1 is about 6 feet per second (2 feet in 8 frames), about 3 times that observed in the Zapruder film. In another case (target # 5), material jettled out of the entrance hole as well as the exit, and the recoil backwards was noticeably slower (about 4 feet per second). Matter appears to be sprayed in all directions around the melon, and the subsequent recoil does suggest that the shot came from the left, instead of the right. As Thompson and others have pointed out, considerable matter from President Kennedy's head was ejected backwards and to the left; our experiment shows that a bullet can produce a jet from the entrance hole as well as from the exit, and still produce a recoil toward the rifle. We feel that the similarity between our film of target # 5 and the Zapruder film is quite strong. (The Zapruder film is owned by Life and cannot be reproduced here. All of the frames around the head shot are published in Volume 18 of the Hearings of the

FRAME 1

TARGET
24 FRAMES PER SECOND
DIRECTION OF BULLET: →



apparently corrected for, but I do not understand in detail what was done. I would also like to be convinced that the error estimates were properly done. My own impression on viewing the Zapruder film was that the forward motion was consistent with the continuation of a forward slump that was apparent in previous frames.) Regardless of any questions about the magnitude of the forward motion (which probably could be resolved if first-generation slides of the relevant frames were made available), the forward motion cannot be used as evidence for a shot from the front.

It should be emphasized that we did not attempt to simulate the conditions of the assassination, but only to show that a recoil towards the gun is physically possible. A more complicated experiment, using high-speed photography and an animal head from a slaughterhouse, has been suggested, but I do not feel that such an experiment would allow us to make a conclusive statement about the assassination.

We do feel that a taped melon is not an unreasonable simulation of a person's head, but we are certainly not claiming that our experiment alone proves that the President was shot from the rear. We do conclude that, contrary to what many critics of the Warren Report have claimed on the basis of intuition and an inadequate analysis of the physics of the situation, the motion of the President's head as recorded in the Zapruder film is completely consistent with a single shot from the rear. Dr. Alvarez feels that the conclusion should be stated more strongly, although no one can prove by examining the Zapruder film that the shots came from the fifth floor of the Texas School Book Depository, the direction of the material ejected from the President's head, plus the direction of motion of his head and body immediately thereafter, are just what our experiments would lead us to expect if he had been shot from that location.

We do not now have a detailed explanation of how a bullet interacts with a target to produce a high-momentum forward jet, and we do not think it is necessary

to analyze this interaction in detail; we feel that the experimental results presented here do basically resolve the issue by providing a counterexample to the hypothesis that backward motion could be produced only by a shot from the front. As noted above, although Dr. Alvarez felt confident that he understood what would happen in the test, we did feel that no such explanation would be at all convincing unless it could be experimentally verified. Fortunately, the experiment was a rather easy one; thus we were led to ask why it had not been done before. How did the critics of the Warren Report (myself included) come to accept a conclusion that was not correct, but nonetheless so convincing that we did not feel the need to test it experimentally? Why did neither the Warren Commission nor its defenders come up with this rather straightforward way of supporting the conclusions of the Commission? As we turn to these questions we see how a rather simple bit of scientific investigation can be obscured, more or less unintentionally, by extraneous considerations: in the case of the critics, insufficient appreciation that what is completely obvious need not be true; on the other side, what was at best bureaucratic, political, and organizational obstructions coupled with a reluctance to examine evidence that strongly appeared to contradict the quickly-reached conclusions of the Warren Commission.

We have already discussed the logical basis of Thompson's analysis. Not being a physicist, he had to rely on the conclusions of experts. These experts may or may not have been aware of the possibility that forward-going fragments were carrying off more than the incident momenta, but if they were they rejected it. Thompson was hardly in a position to make an independent evaluation of that possibility, and I think that is in his book. In fairness to Thompson, it should be noted that Dr. Alvarez' explanation is hardly obvious - when he was first asked about the head snap after his work on other aspects of the Zapruder film for CBS, his first thought of neuromuscular, rather than physical,

explanations. In addition, the report of the Warren Commission has been criticized by many of the others that had been published. The head snap was brought to public attention by the critics, after having been ignored by the Warren Commission (as we shall see), and many of them were permissively and eloquently about what the Zapruder film showed. We quote some of these comments here, not to deprecate the critics, but to show the significance that has been attributed to this evidence (perhaps the strongest item of incontrovertible physical evidence that appears to contradict the fundamental conclusion of the Warren Report), and to place in perspective our analysis of the failure of the Commission and its defenders to examine this matter.

In November 1964, two months after the Warren Report was published, the Hearings of the Commission were released. The black-and-white stills from the Zapruder film published there gave critics their first chance to study all the frames at the time of the head shot. (This was slightly complicated by the poor quality of the reproduction and by the exchange of the two frames immediately after the impact.) The backwards head snap can be detected, but becomes striking only in the film. One of the earliest written reports of a viewing of the Zapruder film by a critic is that of Thomas Stams, who saw the film at the National Archives in September 1965. He wrote (quoted in Accessories After the Fact, page 33):

Of greatest importance in the film is the sequence of the fatal shot and its aftermath. This sequence shows President Kennedy thrust violently back against the rear seat, from which he bounces forward and spins off to his left into Mrs. Kennedy's arms.... The sudden explosive violence with which President Kennedy is slammed back against the rear seat is unmistakable. It is within the realm of speculative possibility that the violent backward thrust of the President was caused by the sudden acceleration of the limousine.... The violent backward thrust of President Kennedy occurs, to the eye, at the instant of impact of the fatal shot. The two events appear to be simultaneous and to have the obvious relationship of cause and effect. The service of truth requires no other explanation....

Writing in late 1966, Sylvia Meagher commented on subsequent analysis of this film:

Without question, the motion of the viewers [after Stams] has carried the Warren Commission to the left. The Warren Commission and Gaston Penzi conclusively demonstrated that the head snap was caused by the position of the body in successive frames. The Warren Commission projectors and projecting one slide upon the screen in 1964, in June 1966, at my suggestion - P.L.S. The resulting motion picture, published in Life magazine, August 1966, was the Warren Commission's most effective and irrefutable proof that the bullet that sent the President's head backward and to his left was fired in front of and to the right of the car and not from the Book Depository. Some six months after the Warren Commission was published no spokesman for the Warren Commission had challenged the data or the accompanying conclusion that the film shows the head snap from somewhere on the grassy knoll. (Accessories After the Fact, page 33)

The study by Dr. Riddle on which Thompson based his conclusions, as noted above, was quoted at length in an article by David Walsh and David Lifton (Ranarita, January 1969). The authors agreed with Riddle's conclusion:

On the assumption that a neuromuscular reaction can be ruled out...., any motion of the body would be governed by the laws of physics, which govern the collision between any two objects. The motion of Kennedy's body in frames 313-323 [impact is in frame 313] is totally inconsistent with the impact of a bullet from above and behind.... (Page 89)

Dr. Riddle noted, correctly, that "we must be careful how we apply these principles [conservation of momentum]. It is only in cases where the impact is with bone, i.e. a rigid part of the body, that a definite statement of the resulting motion can be made." We conclude that he erred in saying that "this is true of the present case, but not, for example, of a hit in the stomach."

Once one regards the problem as the collision of two objects which do not break up, and neglects the relatively small amount of bone and other material that is driven forward, the erroneous conclusion must follow.

Independently from Thompson, Harold Weisberg noted the forward and backward motion of the President's head. In May 1969, he wrote:

Close study of the Warren Commission film and the stills and I cannot say but that the Warren Commission's analysis of the head snap is wrong. The head snap is not a result of the bullet's impact on the head. It is a result of the bullet's impact on the neck. The head snap is a result of the bullet's impact on the neck. The head snap is a result of the bullet's impact on the neck. (Photographic Evidence, page 24)

The Warren Commission did not permit to act as counsel for Oswald's

interests during its investigation, touched on this point in March 12
judgment:

When the bullet struck the President's head, as one can see from the photographs, he was thrown to his left and towards the rear of the limousine. How could the Commission explain that sudden violent move of the President's body directly to the left and to the rear? So long as the Commission maintained that the bullet came almost directly from the rear, it implied that the laws of physics vacated in this instance, for the President did not fall forward. (Page 55)

New Orleans District Attorney J.M. Garrison picked up what others had noted in the Zapruder film:

A number of reliable witnesses testified [to the Warren Commission] that they heard shots ring out from behind the nickel fence [to the front and right of the President] and saw a puff of smoke drift into the air. Additional evidence supporting this can be found in the Zapruder film published in Life, which reveals that the President was slammed backward by the impact of a bullet; unless you abrogate Newton's third (sic) law of motion, this means the President was shot from the front. (Playboy, October 1967, page 165)

In the same interview, Garrison claimed that "our office has developed evidence that the President was assassinated by a precision guerrilla team of at least seven men, including anti-Castro adventurers and members of the paramilitary right." In March 1969, it took a jury less than one hour to acquit Clay Shaw of conspiring to murder the President; even among those Warren Report critics who had remained open-minded about Garrison despite his consistent distortions, errors, and wild speculation, few thought he had presented a substantial case against Shaw. However, it was widely felt that he had presented a strong case against the Warren Commission's version of the assassination. One of the points he emphasized heavily was the head snap after the fatal shot. He had subpoenaed the Zapruder film from life in March 1968, and showed it several times during the Shaw trial. Milton Bener wrote that "seasoned reporters ... expressed the opinion that Shaw would be convicted by the blood and gore of the Zapruder film which the jury watched in rapt fascination" (The Garrison Case, page 255). The New Orleans Times-Picayune reported on one

of the early showings of the film as follows:

There was intense anticipation as the audience waited for the second shot. A reddish puff - that appeared to be smoke - exploded on the screen. There was a gasp from the audience. Did the President fall forward or backward? Heavens looked intently, for this is the key on which hinges the controversy. (Feb. 14, 1969, p. 14)

(By just asking which way the President fell, the reporter must have been straining to be impartial. You don't have to look very intently to see that he did not fall forward.)

Shaw's lawyers reluctantly found themselves in the unenviable position of defending not only their client but the Warren Commission. They were unable to challenge the prosecution successfully on the matter of the head snap. Dr. John Nichols testified that the backward motion "is compatible with a gunshot having been delivered from the front" (Times-Picayune, Feb. 13, 1969, page 44); transcript, Feb. 17, pages 43-44). Irvin Dymond, chief counsel for Shaw, asked on cross-examination if that motion could have resulted from an acceleration of the car (there was none at that instant); he asked Nichols if he had considered the possibility of a delayed reaction, or the effect of the wind. (States-Item, Feb. 19; transcript, Feb. 17, pages 69-72) Other testimony on the head snap was given by FBI agent Lyndal Shaneyfelt, who described the examination of the Zapruder film which he had done on behalf of the Warren Commission; his testimony is considered below, in the analysis of the Warren Commission's failure to analyze this point.

The importance that even the anti-Shaw forces placed on the head snap is suggested by a story which appeared in the States-Item:

The States-Item clearly demonstrates that at the time the Warren Commission was formed, the States-Item argued: "If the strike came from the rear, more than one direction, the strike would be a mystery." One sequence - which was shown in a States-Item - clearly shows the President falling backward from the limousine. The Warren Commission Report has already met this objective, stating that Kennedy fell backward because his

(Feb. 21, 1969)

... the car did not stop. The car continued to move forward. The fatal shot was fired from the front of the car. King's attribution of this shot to the Warren Report is a complete fiction.

... had a similar tone.

... seem to show Kennedy jerking back as if hit from the front. ... have testified this could have resulted from sudden movement of the President's car. But it was the total impact of the shot that really worried Clay Shaw's lawyers, who have repeatedly been asked when they argued that the events in Dallas are not as described in the proceedings. 'You think the jury will think it's such a terrible crime that somebody should pay for it?' defense attorney William Brennan was asked. 'Yes,' he answered. 'That's exactly what I'm afraid of.'

(New York Times, Feb. 24, 1969, page 33)

The jurors and spectators alike sat on the edge of their seats when Abraham Zapruder's film of the assassination was shown for the first time publicly and Zapruder himself described what he had witnessed. The prosecution obviously made a telling point with the film, run before the jurors at normal speed and once frame-by-frame. When what appears to have been the second shot hit the President his body was flung backward. This is the basis of Garrison's argument that the fatal shot came from the front, but while it bolsters the district attorney's case it hardly is conclusive. An FBI analyst [Shanoyfelt] pointed out later that fragments flew forward on a vertical (sic) line from the President's head, indicating that the bullets struck him from behind as the Warren Commission contends. But Garrison's lieutenants take advantage of every opportunity to rerun the gris film for the jurors. Their explanation is that they want to establish where each new Dallas witness was at the time the gunshots were fired. But their real intent is transparent: to bury each juror's mind the picture of the President's head and body jerking backward.

(Times-Lost Service in the San Francisco Chronicle, Feb. 17, 1969, page 10)

... the head snap was discussed in a ... legal proceeding, a hearing in Washington on Garrison's attempt to ... to the photos and X-rays which had been made during the Kennedy ... and then suppressed. Dr. Cyril Wecht, a forensic pathologist,

... that he considered it "highly improbable" that the President's ... was consistent with a shot from the rear. He was cross-examined by ... Attorney General Carl Erdley, who appeared to have in mind some ... other than a neuromuscular reaction or an acceleration of the car ... based on the physics of colliding objects).

Q. (Erdley) And if I threw a ball at that wall, the ball would bounce back, wouldn't it?
A. (Wecht) Yes, sir.
Q. And isn't that what is likely to have happened when King was hit from the front of the skull - that the body would go backward because of the resistance?
The Court (Halleck) - Following your analogy, the ball would bounce back.
Mr. Erdley - It won't bounce. I am suggesting this. I am not a pathologist, and I think I got a D in physics.

Judge Halleck then brought up the idea of a jet-propulsion reaction which Wecht admitted was a possibility. Obviously he did not make a suggestion conclusive, for he later ruled that enough evidence had been raised to entitle Garrison to have access to the Warren Report. (By that time Garrison had let the case become moot.)

As part of their extensive examination of the Warren Report with its critics in July 1967, CBS purported to present a scientific explanation of the head snap. The CBS explanation, as it was presented to an audience of perhaps 30 million, frankly defies adequate summary or paraphrase. The transcript is in full (from the transcript as reprinted in Should the Warren Report be a Warren Report, by Stephen White, one of the associate producers of the program):

COMMENT: In Abraham Zapruder's film of the assassination, the fatal shot appears to move the President's head back. The transcript contained this can only mean the shot came, not from behind the Depository, but from somewhere in front. Not for the first time, for the last in these reports, we find exactly the opposite in disagreement.

We put the transcript of the Warren Report in front of the

RAYSON: But now, the explosion, this white explosion, occurs forward of the President. Now, wouldn't that indicate the bullet coming from the front?

WYCKOFF: No, quite contrary. It does indicate that the bullet was coming from behind.

RATHEN: Well, you're aware that some critics say that by the very fact that in the picture you can clearly see the explosion of the bullet on the front side of the President, that that certainly indicates the bullet came from the front.

WYCKOFF: Well, I don't believe any physicist has ever said that. This picture might explain the principle that we've been talking about just a little bit more clearly. It's a picture taken in a millionth of a second, of a thirty calibre bullet being shot through an electric lightbulb. The bullet was traveling from this direction, entered the lightbulb here, passed through and caused a rather violent explosion to occur on the exiting side, and it's very similar to the situation in the Zapruder Kennedy assassination films.

CHONITZ: That is one explanation from a physicist as to how a head could move backward after being struck from behind, which seems to many laymen not possible. Forensic pathologists are experts in the examination of victims of violent death, both medically and legally qualified. Dan Luther put the matter to one of them, Dr. Cyril W. Wecht, professor at Duquesne University.

CYRIL W. WECHT: I have seen too many biological and physical variations occur in forensic pathology to say that it would have been impossible. I say that it is quite unlikely. I say that it is difficult for me to accept, but I would have to admit that it is a possibility that his body could have moved in that direction after having been struck by a bullet that hit him in the back of the head.

The main problem is obviously that, despite Cronkite's introductory comments and summary, Wyckoff says absolutely nothing about the motion of the President's head. Wyckoff was correct in noting that spalling is suggestive of a shot from the rear, but in fact material was ejected both forward and backward from Kennedy's head, and our experiment has shown that there can be a spray of material from both the entrance and exit holes. Can rather than completely confused the issue by suggesting what, as far as I know, no responsible critic has claimed - that the location of the "explosion"

indicates the direction of the bullet. To top things off, a searchlight light bulb is obviously a very poor simulation of the President's head.

In the text of his book, White managed to come quite a bit closer to a reasonable explanation of the head snap. He was aware that conservation of momentum is not always a simple law to apply, and that the backward motion, although implausible, is not in itself a violation of that law.

The only real law involved is the law of conservation of momentum, which establishes the relationship between velocities (and velocity involves both speed and direction) and masses before and after collision. The relationship is a simple one: The masses must be the same before and after.

The velocities and masses can be measured quite simply when the collision takes place between a golf ball and a golf club. With a skull and a mallet, the relationship is not so simple. The skull is a bony structure within which there are liquids and solids under restraint. A bullet entering the skull sets up all kinds of forces and counterforces. If they are such as to drive forward, at high velocity, a part of the skull, it may well be that the rest of the skull will move backward.

In fact, of course, if part of the skull is driven forward fast enough, the rest must - not may - move backward.

Obviously unsure of this physicist's explanation, White goes into a long discussion of the possible effect of neuromuscular tension at the time of impact in determining the subsequent motion:

Thus most physicists will agree that considering only the interaction of a bullet and a human skull, there is a possibility, although only a slight possibility, that the skull will move backward after the impact. But the matter goes further than that. The interaction that took place was between a human being and a bullet, and superficial physics will not do to explain it.

... the skull will depend on the neuromuscular state of the man who is struck. It may be longer a simple collision, but a counterforce.

There is indeed a mystery in the motion of the President's head after impact, but it is the ordinary kind of mystery that proceeds from inadequate knowledge. There is nothing in that motion that would lead a physiologist to deduce from it the direction of the bullet.

Although such arguments are hard to prove or disprove, we have shown that they are not needed in this case. White's conclusion - which immediately follows the last-quoted sentence - is basically correct, because of or in spite of the fact that it does not follow from his physiological arguments:

Given the fact that the bullet together with fragments of skull carried away most of the momentum along the direction of motion, the skull itself might have moved in any direction at all.

We have seen how Thompson came to the wrong conclusions based on careful measurement and expert scientific opinion. In fairness, we should not praise CBS for coming close to the correct solution without pointing out how inadequate their procedures were. For example, White noted that

To bear this out, a photograph was taken at one millionth of a second showing a bullet passing through an electric light bulb; an explosion occurred on the side of the bulb away from the point of entry of the bullet. That explosion, if the bulb were not restrained, might have driven the bulb slightly back. None of this is at all mysterious; it is ordinary high-school physics.

What reason could there have been for not showing such a film with an unrestrained bulb? Certainly CBS had the facilities and money for an experiment far more elaborate than ours. I suspect that despite White's claim that this is "ordinary high-school physics," he considered his own solution so unlikely that it was not worth trying to check it out experimentally. (What seems more likely is that the theory presented in his book did not occur to White until after the embarrassingly bad "explanation" had been presented on the TV program.) Perhaps it is not unfair to suggest that if an experiment like ours had seemed likely to support the Warren Report, CBS would have done it.

(Although Dr. Wyckoff did eventually answer several of the questions I raised in a letter to him, he never explained what he thought of the backward motion. He did tell Monroe Koen informally that he had not been asked to study it and had not done so. Thus, I do not think that the substitution of a discussion of the spalling effect for one of the head snap can simply be attributed to a massively botched-up editing job.)

While we were deciding how to verify and present our conclusions, and waitin' until melons were available, I ran across one book written on the Kennedy assassination which indicates a good understanding of the "rocket" effect which can explain the backward motion. William Hanson is a retired Air Force officer whose interest in the technical aspects of the assassination was spurred by the four-part CBS program. Based on a study of some of the eyewitness and medical testimony, and his own extensive experience with the effects of gunshots, he wrote The Shooting of John F. Kennedy: One Assassination, Three Shots, Three Hits, No Misses. (Naylor Co., San Antonio, 1969)

Hanson attributes the apparent backwards motion of matter from the head wound to the fact that the car was moving at about 15 miles per hour (Page 83). He explains the head motion in terms of the "confined liquid" and "jet propulsion" effects. The former is the fact that pressure applied to an incompressible liquid is transmitted throughout the entire surface of the container. (This is a consequence of Pascal's Law.) He describes the "jet propulsion" effect as follows:

If a high-velocity bullet is fired into a closed container filled with a liquid and there is a weak spot in the container, it will burst explosively, but the initial pressure buildup will force liquid to blow out or jet out of the weak spot first, which, as it occurs, will force the container to move by jet propulsion / i.e., conservation of momentum / in the direction opposite to the liquid jetting out through the weak spot. Both "confined liquid" bursting effect and "jet propulsion" effect can be demonstrated (pick a safe place) by firing a high-velocity hunting rifle bullet into a one gallon plastic bottle completely filled with water that has had its spout opening sealed over with some very thin material such as wax paper. No matter where

the bottle is hit, provided the bullet penetrates the bottle, it will always move away from the spout (the weak spot) while blowing to pieces....

The only flaw in Hanson's case is that he did not realize that the weak spot through which jetting occurs need not exist before the impact.

In our preliminary experiments, we did shoot at water-filled plastic bottles, but noticed no jetting through the entrance and exit holes. That clearly can occur in taped melons, and - we are confident - did occur in the President's head. (Hanson correctly noticed the blowout effect, but was forced to conclude that the President's skull had been weakened by a glancing wound from the first shot fired; he suggested that all evidence of this impact was obliterated by the fatal shot. There is some eyewitness testimony that can be read as favoring such a hypothesis, but not very much. See pages 88, 168-169, 173, 182 ff., 198, and 202 of Hanson's book.)

Having critically examined various analyses of the head snap set forth by both opponents and defenders of the Warren Report, we now turn to the views of the Commission itself. Rather, we will try to understand how the Commission managed not to consider this question - for (to the best of my knowledge) there is no evidence at all that the head snap was ever considered by the Commission. The Warren Report itself makes absolutely no reference to it. In all of the 26 volumes of Hearings, and in that part of the Commission's files at the National Archives which I have seen, I know of only one reference: an FBI report, describing another film of the assassination, notes that

Mix photographed the left side of the Presidential car with Mrs. Kennedy in the foreground waving when the President's head suddenly snaps to the left and the car picks up speed as a man jumps on the left foothold.

The Commission concluded that "there is no credible evidence that the shots were fired from the Triple Underpass, ahead of the motorcade, or from any other location [other than the School Book Depository]." (Report, page 19) This description of the eyewitness and medical testimony (even excluding the head snap

evidence) is comprehensible only if "credible" is redefined to mean "believed (by the Commission)" rather than "believable."

The Commission's investigation did touch on several areas which might have been expected to result in interest in the head snap. At the Commission's request, personnel at Eggenwood Army Arsenal shot several human skulls filled with gelatin; they managed to duplicate reasonably well the damage done to the President's skull and the fragmentation of the bullet (WR 585-6, 5887-90). Although they did view the Zapruder film (5906, 5H142), it appears that they did not give any consideration to the motion after impact.

The Zapruder film was studied extensively for and by the Commission. One of the main objectives was to determine when the President was first hit and when Governor Connally was wounded (to see if the time interval was consistent with a single bullet or two shots from Oswald's rifle) (WR 96 ff.). FBI expert Lyndal Shaneyfelt studied the film in order to determine the location of the car at the time of the fatal shot (among other things). (WR 109-110, 5H159-160) In his testimony, Shaneyfelt did not make any reference to evidence in the film about the direction of the fatal shot. When he testified in the Shaw trial, he indicated that he based his opinion that the shot had come from the rear on the direction of the excellent fragments; that is, he apparently did not consider the head snap. (Unfortunately, his testimony has not yet been transcribed. The contemporary newspaper reports are somewhat ambiguous as to whether he noticed the backwards motion, but he clearly did not base his opinion on it. The approximate transcripts from the two New Orleans newspapers are reprinted in Appendix 4.)

In a memorandum for the record in April 1964, Warren Commission Assistant Counsel Melvin Eisenberg noted that

Over the last several months, we have held conferences in an attempt to determine the frames in the Mix, Zapruder, and Muchmore films which portray the impact at which [sic] the third shot struck the President.

Present at all these conferences were Inspector Leo Gauthier and Mr. Lyndal L. Shaneyfelt of the FBI, John Joe Howlett of the Secret Service and Messrs. Redlich and Eisenberg of the Commission staff. Also present at most or many of these conferences were Messrs. Spector and Berlin of the Commission staff, several unidentified assistants of Inspector Gauthier, Inspector Kelley of the Secret Service and Inspector Malley of the FBI. The consensus which emerged from these conferences is that the impact of the third shot is portrayed in frame 313 of the Zapruder film, frame 24 of the Nix film, and frame 42 of the Kuchmore film....

One can wonder why several conferences, involving maybe a dozen people, were required for the determination of such a relatively simple fact. Perhaps the memo does not accurately reflect the reason for the conferences. In any case, it is almost impossible to believe that nobody noticed the backward motion during any of these meetings, where the relevant frames were being examined. If the head snap was noticed, a serious and independent investigative body would have been compelled to call for a detailed study.

It is possible that the FBI experts who studied this film on their own did not notice the head snap. If they had noted it, they may well not have pointed it out to the Commission. It is crucial to any understanding of the Commission's work, and its relations with its investigative arm, to realize that the FBI essentially did just what it was asked to do, and very little more. (For example, the Commission asked the FBI to determine the date of the issue of the Militant in the photo of Oswald with his rifle; the FBI did this and sent over a copy of the paper (Shaneyfelt Exhibit 22A). They did not point out that there was a letter from "L.H., Dallas" in that issue of the Militant - obviously important evidence in connection with the questioned authenticity of the photograph. I am confident that if the FBI had been investigating this on their own, the letter would have been checked out.) Many of the FBI reports reflect a strong effort to avoid drawing conclusions for the Commission; agents were generally able to transmit their opinions by means of careful selection of relevant facts. As J. Edgar Hoover has recently reaffirmed in connection with the investigation of the Kent State killings, "it has long been the policy of

this bureau not to draw conclusions in any case investigated by us" (Time, August 24, 1970, page E1).

Several critics have noted this omission by the Commission with incredulity and skepticism. Thompson quoted Assistant Counsel Wesley J. Liebeler: "It's only since the critics have raised this point," Liebeler conceded, "that anybody has ever looked at it closely." (Six Seconds, page 86)

Returning to the results of our experiment, let us examine the limitations of our conclusion. We claim that the motion of the President's head and the fragments ejected by the bullet are consistent with a single shot from the rear. As noted above, we are not claiming that what is observed could have been caused only by a shot from the rear.

Our conclusion concerns only the motion of the President, not his wounds. A detailed analysis of the contradictory evidence in this respect would not be appropriate here. (See, for example, Six Seconds in Dallas, and Post Mortem, by Harold Weisberg.) In brief, almost none of the medical evidence can be accepted un skeptically. The autopsy was performed under conditions unfavorable to proper forensic inquiry - for example, the doctors were told, maybe by Navy Surgeon General Edward Kenney not to dissect the President's non-fatal wound. A panel of experts who viewed the suppressed autopsy photographs with the specific purpose of resolving doubts that had been raised by critics managed to bring up as many new problems as they solved. For example, the entrance wound at the back of the skull was described in the autopsy report as being "slightly above and to the left of the occipital protuberance." In 1967, the autopsy surgeons explained that "the photographs show the wound to be slightly higher than its actually measured site" (1967 report, page 3). The panel of experts located it 100 mm - about 4 inches - above the occipital protuberance, without explaining the discrepancy. To summarize: the available evidence on the President's wounds is too confused to allow us to decide whether, on balance, it supports our

hypothesis (and the Commission's) of a single shot from the rear. Certainly our experiment does not resolve the contradictions in the evidence.

Our work has demonstrated that the fatal shot probably was fired from the direction of the School Book Depository Building, a single gun man for any single-assassin theory. To account for the other shots fired, the Warren Commission relied on the "single-bullet" hypothesis and a third shot that missed. The single-bullet theory (which has been studied at length elsewhere) is, we feel, not a likely explanation of the observed facts. We feel that the most likely hypothesis which is consistent with just one assassin is as follows: the first shot was fired early, about Zapruder frame 190; it struck President Kennedy in the back or neck, was deflected as it passed through, and exited from the car without striking anything else. The second shot caused all of Governor Connally's wounds; this is the bullet which was recovered at the hospital with some deformation but little apparent damage. The third shot, fired from the rear, struck the President in the head.

This theory (which has been developed in a paper by Don Olson) is based in part on evidence in the Zapruder film that there was an early shot; the jiggling of Zapruder's camera at about frame 190 (which Dr. Alvarez found and attributed to a shot), correlation of eyewitness testimony with the apparent reaction to a shot by spectators (especially Mrs. Kennedy), etc. However, this hypothesis is not consistent with all of the evidence presented by the Commission in favor of the "single-bullet" theory, which it described as "very persuasive" (WR 19), nor is it consistent with the considerable eyewitness testimony of suspicious activity on the "grassy knoll." In addition, the origin of the first shot can not be pinpointed in this theory; the Warren Commission noted that a tree in the line of sight made an early shot from Oswald's alleged position unlikely if not impossible. A second assassin, firing from the same general direction, can not be ruled out, especially since no third bullet was recovered for ballistic

comparison with Oswald's rifle. In addition, the Commission interpreted the Zapruder film as showing no reaction by President Kennedy until well after frame 190; their analysis seems to have been inadequate in this area also.

Finally, we emphasize that although our observations tend to support the conclusion of the Warren Report that Lee Harvey Oswald was the lone assassin of President Kennedy, they do not in any way vindicate the work of the Commission itself. Commission supporters have often challenged the critics to come up with "new evidence" - material that was not considered by the Commission. Critics have replied that the old evidence is good enough. In many crucial areas, the unexamined and/or unpublished evidence runs strongly counter to the Commission's claims. I have found several sensitive areas, dealing mainly with Oswald's possibly irregular connections with various government agencies, where the Commission failed to ask for the relevant evidence, and where it seems that such agencies would have been able to withhold important information from the Commission without much danger of being detected. In this case, the Commission failed to properly interpret physical evidence that was available to it; it just happens that they missed evidence favoring their case. The Commission's failure to notice the rather striking evidence of the head snap which points away from their pre-ordained conclusion - much less to find an explanation for it - confirms the absurdity of Commissioner Gerald Ford's claim that "never has a crime been so thoroughly investigated." (Portrait of the Assassin, page 25)

and $E_2 = \frac{1}{2} m_2 v_2^2 = 25.6 \text{ ft}^2\text{-lb/sec}^2$. To get an upper limit, assume that the tissue was pulverized around the hip. Since the weight of the entire body was about 170 pounds (WE 579), the recoiling weight might have been as much as 120 pounds. The average rearward velocity of the upper part of the body might be about 0.8 fps. This would give $P_2 = -96 \text{ ft-lb/sec}$, and $E_2 = 38 \text{ ft}^2\text{-lb/sec}^2$.

It is difficult to estimate the amount and speed of the fragments which were driven forward. Frame 313 shows a reddish blob around the President's head, and a couple of streaks going forward and upward. Their speed can be estimated by noting that they have traveled several feet since the impact, which occurred some time after the previous frame. The clearest streak is perhaps 4 feet long, which means a velocity of at least 4 feet x 18.3/sec = about 70 fps. The actual velocity of the streaking material could be quite a bit greater.

It is clear that all the matter driven forward did not have the same speed. (The presence of matter close to the head shows this.) One fragment from the fatal shot probably caused the small crack in the windshield. (I have no idea how fast a fragment would have to be going to crack but not penetrate the glass.)

Medical reports could provide an upper limit for the amount of matter expelled from the head. (Of course, much of the loss of bone and brain matter recorded in the autopsy could have occurred long after the bullet struck.) I do not know if the skull fragments recovered in Dealey Plaza were weighed. The brain weighed 1500 grams (3.3 lb) after formalin fixation; we may estimate the total weight of the matter driven forward as something less than 1 pound.

If equation (1) is to be satisfied, $m_3 v_3 = m_1 v_1 + m_2 v_2$. From our above estimates, this gives $m_3 v_3 = 40 - (-30) = 70 \text{ ft-lb/sec}$. (I have rounded off the numbers.) If 1 pound were driven forward at the 70 fps we calculated from the streaks, this equation would be satisfied.

A more reasonable solution can be obtained by considering three fragments, rather than just one. Consider one-quarter of the bullet going forward at essentially the same speed it originally had, a couple of ounces at 500 fps, and a pound at just 10 fps:

m (lb)	v (ft/sec)	p = mv	E = $\frac{1}{2}mv^2$
0.006 ($\frac{1}{4}$)	1000	10	9,720
0.1	500	50	12,500
1.0	10	10	50
	Total:	70	22,270

Again, momentum conservation is satisfied. (From the last column, we can see that energy conservation can be satisfied with a reasonably small ϵ . From our calculations, $E_1 = 37,100$; $E_2 = 25.6$; in the example with 3 fragments just tabulated, $E_3 = 22,270$. This corresponds to $\epsilon = (22,270 + 25.6)/37,100 = \text{about } 0.6$. For $m_3 = 1.0 \text{ lb}$, $v_3 = 70 \text{ fps}$, ϵ is even smaller, about 0.14. This confirms the statement in the text that there is plenty of kinetic energy available to produce the "rocket motor" effect.)

These calculations, which were done before our experimental tests, convinced me that this hypothesis was not unreasonable; i.e., not obviously inconsistent with the evidence at hand. I do not think that more refined calculations would prove anything; the experiment has shown that under certain circumstances a backward recoil does occur.

APPENDIX 2 - THEY SHOOT MELONS, DON'T THEY?

(Or, Six Seconds in San Leandro)

These pictures show the results of our final shooting session. The targets are taped-up melons, weighing 1.1 to 3.5 pounds each. Targets 1-3 were placed at ground level, on the board which is on the side of the support away from the gun. Targets 4 and 5 were placed on top of the wooden support, to ensure that the melon would not bounce up, as it might if it were shot from above. (The support is about 2 feet high.) Target 6 was suspended by a single piece of filament tape from the edge of the top away from the rifle; target 7 was suspended from the edge towards the rifle. The film (super-8 mm.) was taken at a setting of 24 frames per second.

The next two pages are Xerox copies of prints from slides which were made by cutting up a copy of the movie film. The earliest frame in each sequence is at the upper left. Color prints can be obtained from me upon request, at cost: 35¢ for 3 x 5", \$ 1 for 7 x 10", etc. A duplicate of the entire film is \$ 6. (The prints show the results as well as the film.) The 7 targets are on 5 slides, as follows: Slide 1 (target 1); 2 (2-3); 3 (4); 4 (5-6); 5 (7). A few copies of this report are being distributed with prints which were done backwards; note the orientation of the L-shaped support. In the Xerox copies, the rifle is to the right.

The results shown on the next two pages are summarized here:

Target 1 rolled violently backwards and to the right (relative to the rifleman). A strong forward spray is visible in the first few frames.

Target 2 lost spray forward, a smaller jet upwards and back, and then just slowly rolled over.

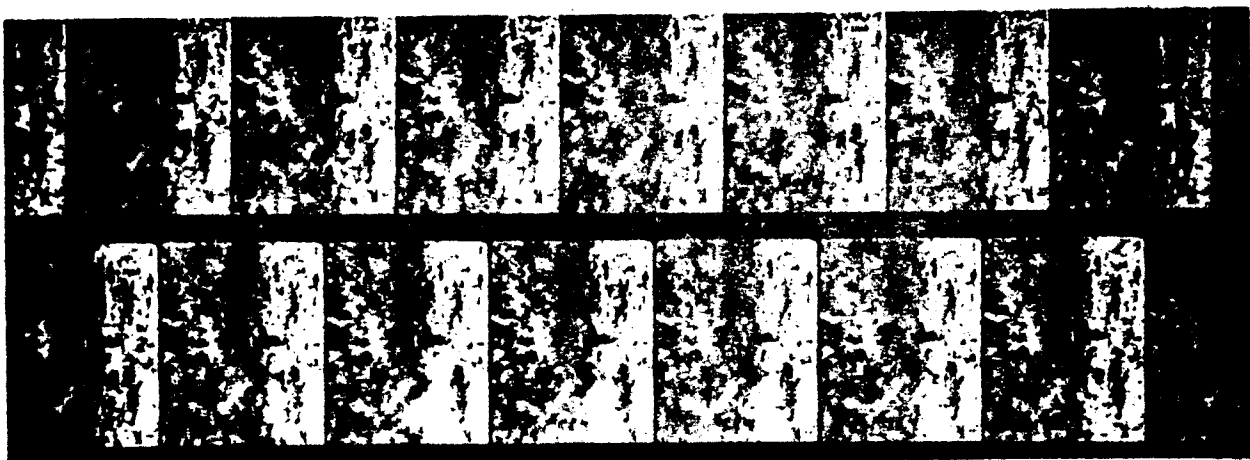
Target 3 rolled about a foot backwards.

Target 4 showed a very clear backward recoil after a forward jet. (A Xerox copy of a negative Thermofax print of these frames is Figure 1 in the body of this report.)

In target 5, there is a clear backward jet as well as a forward one. The backward one is less strong, so the melon recoiled backwards.

Target 6 was driven back and to the right, into the side of the wooden rig. Only the spray can be seen in the film.

Target 7 sprayed forward and recoiled back in an arc, held by the tape. After about half a second the tape unwound itself from the rig. This target and # 4 show the rocket effect most clearly.

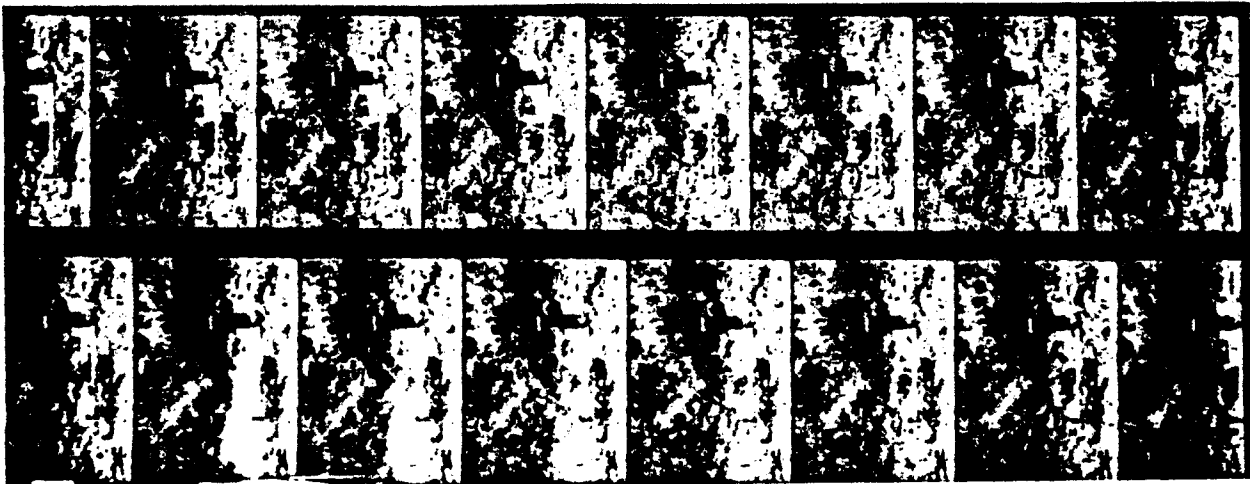


Target # 3

Direction of bullet: ←



Target # 2

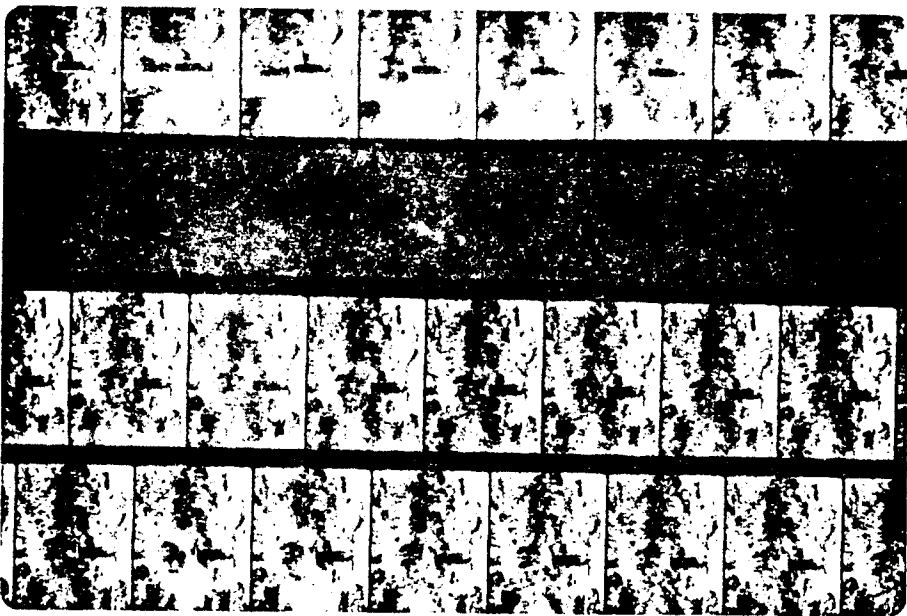


Target # 1



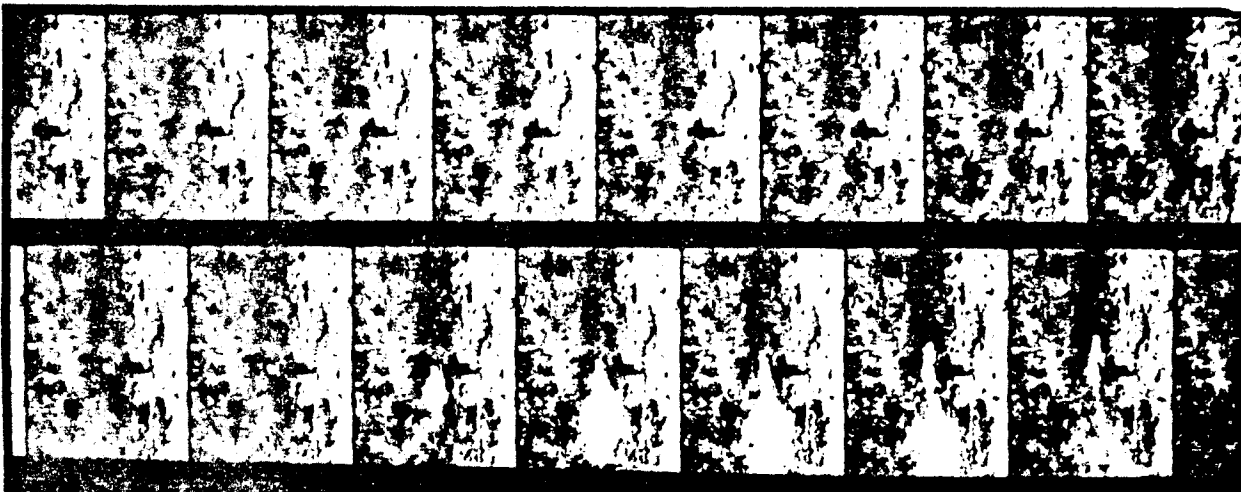
Target # 7

Direction of bullet: ←



Target # 5

Target # 6



Target # 4

APPENDIX 3 - STILL PHOTOGRAPHS OF THE EXPERIMENTAL SETUP AND RESULTS

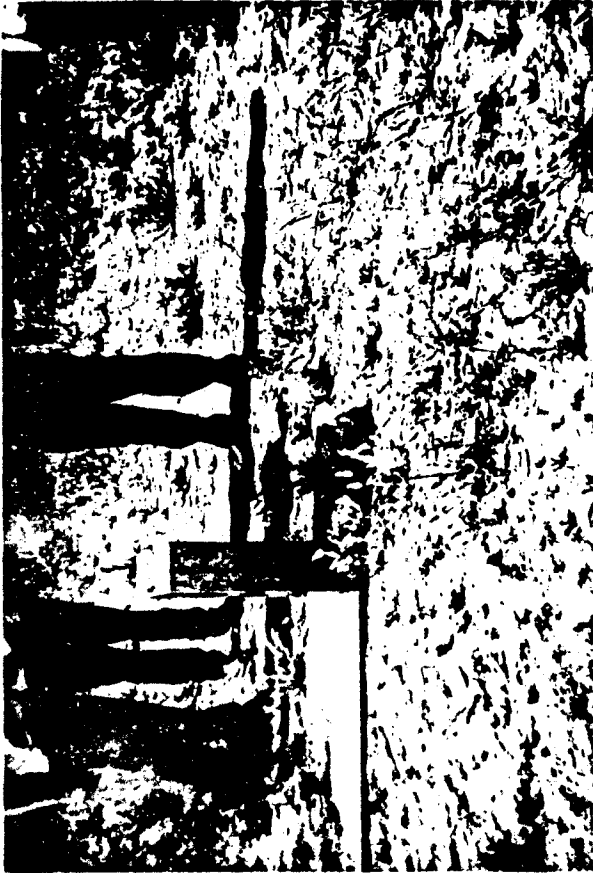
This report includes a Xerox copy of four representative still photos. B16 (lower left) shows the general setup, looking from behind the target towards the shooter's position. For comparison with other photos, note that the horizontal leg of the L-shaped target support extends away from the rifle. The movie camera is out of sight to the right. Target # 5 is resting on the top of the support. C1 was taken as the shot was fired and shows the recoiling melon in flight. C2, taken from the direction of the movie camera, shows where the melon came to rest. (The vertical lines painted on the support are 2 and 6 inches long.) In C4, a stick indicates the entrance hole; the larger exit hole is also visible.

The rest of the 64 photos we took can be obtained from me at cost upon request. Xerox copies (at 6¢ per page of 4) or standard prints are available.

A brief catalog of the photos is presented here:

A1 through A24 were taken at the second of the three experimental sessions. The targets in A6 through A11 were rubber balls filled with gelatin; they tended to go away from the gun, but not in a direct line. The film did not show much of a forward jetting of material. A11 through A16 show plastic bottles filled with water as targets; they tended to explode. The last target is a pineapple, taped up but not thoroughly; it shattered, with the largest piece going perpendicular to the bullet path and one major fragment driven back toward the rifle.

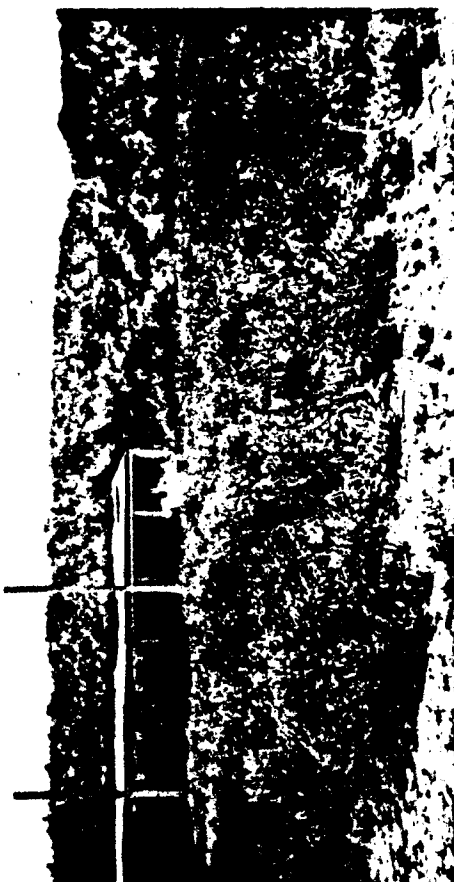
The B and C series were taken at the third session, as were the films presented in Appendix 2. B5 through B9 show target # 1; B10 and B11, target # 2; B13 and B14, target # 3; B15 through B19, target # 4; C1 through C4, target # 5; C5 through C9, target # 6; C10 through C14, target # 7. C12, which was taken by snapping the shutter in reaction to the sound of the shot, corresponds to about 5 frames after impact; it shows the melon held by the tape, which is almost horizontal, after having recoiled backwards.



C2



C4



C1



B16

APPENDIX 4 - TESTIMONY OF LYNDAL SHANEFELT IN THE TRIAL OF CLAY SWAN

From the New Orleans Times-Picayune, February 15, 1969, page 12-231

.... Shanefelt said he and FBI ballistics expert Robert A. Frazier went to Daaley Plaza May 24, 1964, to re-enact the assassination, using a car and individuals of the appropriate size of President Kennedy and Gov. Connally. The purpose, he said, was to reposition the limousine if there was any doubt as to the direction of the shots, the sequence of the shots and the location of the limousine when the shots were fired. He said that the Warren Commission had a car and a limousine at the location of the Warren Commission. Dymond asked him if he had any other information. Shanefelt said he had no other information.

"I have not."
On retrial...
If in frame 313...
the distance...
he did not...
On retrial...
In retrial...
he was...
or whatever...
Mass Bond...

From the New Orleans Times-Picayune, February 15, 1969, page 12-231

(Apparent...)
any...
to...
back of...
One...
Kennedy...
everything...
Q - Did...
that hit...
A - Yes...
that hit...
In frame 313...
of his head. In this photograph...

On the car, going forward...
as a limousine with no knowledge of ballistics, this has to mean...
to note...
could be...
Shanefelt to speak from his view as a...
Shanefelt's impression is that the shots came from...
at this conclusion, did you take into...
Kennedy's body in frame 313?
after frame 313?
material streaking through the air?
was something pink streaking...
but also forward.

Shanefelt's impression is that the shots came from...
at this conclusion, did you take into...
Kennedy's body in frame 313?
after frame 313?
material streaking through the air?
was something pink streaking...
but also forward.