This next point is perhaps subtle but it is nonetheless important and I might add it is one often misunderstood by laymen, such as myself. It is an example, I think, of what Chairman Preyer indicated yesterday about commonsense.

The scientists we consulted indicated that under the best possible circumstances, the experiments could only yield a statement about probabilities. That is, there was no way, in their judgment, to prove scientifically that Commission exhibit 399 could not have inflicted the damage attributed to it by the Warren Commission.

The most such tests could establish is that such a series of events, that is, the wounding of both President Kennedy and Governor Connally, could have occurred, not that they actually did not occur. Consequently, the test could only raise a question about probabilities, something we already knew. The tests could not answer the question that everybody wants to have answered, can you prove or unequivocally disprove what happened in Dealey Plaza?

Mr. Sturdivan, who will be our next witness, received an M.S. degree in statistics from the University of Delaware in 1971 and a B.S. degree in physics from Oklahoma State University in 1961. He has studied mathematics and computer sciences at the Ballistics Institute of the Ballistic Research Laboratory, Aberdeen Proving Grounds, Md., and he has been a physical scientist with the Wounds Ballistics Branch of the Aberdeen Proving Ground Vulnerability Laboratory since 1964.

Mr. Sturdivan is the author of numerous professional articles and he is a frequent consultant in wound ballistics for such agencies as the Law Enforcement Assistance Administration and the Department of Justice as well as NATO.

Mr. Chairman, it would perhaps be appropriate for me to note now, for those who will follow carefully Mr. Sturdivan's testimony, that during that testimony, certain films will be shown. Those films involve the shooting of live and anesthetized goats. The Army, who prepared the films, has asked the committee to indicate to those who watch them that these experiments are not now being conducted. It also suggested, and I think perhaps rightly, that those who might be of delicate sensibility or small children should not watch these films.

Mr. Chairman, it would be appropriate now to call Mr. Sturdivan.

Chairman STOKES. The committee calls Mr. Sturdivan.

Would you raise your right hand and be sworn? Do you swear the testimony you give before this committee is the truth, the whole truth, and nothing but the truth, so help you God?

Mr. STURDIVAN. I do.

Chairman STOKES. Thank you, you may be seated.

TESTIMONY OF LARRY STURDIVAN, PHYSICAL SCIENTIST, ABERDEEN PROVING GROUND VULNERABILITY LABORATORY, ABERDEEN, MD.

Chairman STOKES. The Chair recognizes Counsel Charles Mathews.

Mr. MATHEWS. Mr. Sturdivan, would you state your name for the record?

Mr. STURDIVAN. Larry M. Sturdivan.

Mr. MATHEWS. What is your occupation?

Mr. STURDIVAN. I am a research physical scientist.

Mr. MATHEWS. How long have you been employed as such?

Mr. STURDIVAN. Over 14 years.

Mr. MATHEWS. And where are you employed, Mr. Sturdivan?

Mr. STURDIVAN. At the Chemical Systems Laboratory, the Edgewood area of Aberdeen Proving Ground, Md.

Mr. MATHEWS. What is Aberdeen Proving Grounds? That is, what is its function and purpose?

Mr. STURDIVAN. Located at APG are a collection of a great number of U.S. Army agencies who conduct research development test and evaluation of weapons, vehicles, and other equipment for the Army and for other DOD agencies, and other Government agencies.

Mr. MATHEWS. Within the Edgewood Laboratories of Aberdeen Proving Ground, what specifically are you involved in?

Mr. STURDIVAN. Well, we do work in the general areas of wound ballistics and application of mathematics to chemistry. In wound ballistics, we do studies on human vulnerability and protective devices, which includes trauma from ballistic projectiles. For example, bullets from handguns, hunting rifles or military rifles, fragments from exploding munitions, such as grenades and artillery; blunt trauma from debris from explosions, for example, or riot control devices, combat simulation devices which have fallen short among troops; blunt trauma behind body armor, that is, bulletproof vests and flakjackets which have stopped the bullets and fragments and other debris.

Mr. MATHEWS. What specifically, Mr. Sturdivan, are your exact duties within your laboratory?

Mr. STURDIVAN. Generally, I'm in the business of producing predictive models of effectiveness of weapons, studying the behavior of bullets inside tissue and tissue simulant and exterior ballistics, of course.

Mr. MATHEWS. Would it be safe to say you study the characteristics of bullets in flight, you study the characteristics of bullets as they penetrate solid masses and you also study the characteristics of bullets once they enter the human body and the effect of those bullets on the human body?

Mr. STURDIVAN. Well, yes.

Mr. MATHEWS. Would you describe that as the wound ballistics field?

Mr. STURDIVAN. Yes, generally, the wound ballistics field is a little broader, and perhaps more descriptive in the thoughts of some. At our laboratory, we try to concentrate on the predictive models of behavior of bullets, particularly the full-jacketed military bullets that we are used to dealing with, their behavior in gelatin tissue simulant. In fact, one of the things I have recently been working on is a predictive model of what the behavior of the bullet would be in gelatin as a function of its physical characteristics, such as mass, velocity, location of the center of gravity and several other esoteric characteristics.

Mr. MATHEWS. But my previous statement would be more or less correct, you are involved in those type of studies; that is, characteristics of bullets?

Mr. STURDIVAN. Right.

Mr. MATHEWS. Are you considered an expert in the wound ballistics field?

Mr. STURDIVAN. I would think so; yes.

Mr. MATHEWS. How many additional experts would you say are presently in the United States or the world, for that matter?

Mr. STURDIVAN. Well, outside of a handful of experts within our own laboratories, there probably are very few, even in the free world. Some people do experiments, research, and various aspects of like blunt trauma from automobile accidents, and things like this, but as far as the whole wound ballistics field, there are very few experts.

Mr. MATHEWS. How many experts would you say are presently residing in the continental United States?

Mr. STURDIVAN. Maybe half dozen, and they are all within our laboratories.

Mr. MATHEWS. And they all work within Edgewood Laboratories?

Mr. STURDIVAN. Yes.

Mr. MATHEWS. How long have you worked in the wound ballistics field?

Mr. STURDIVAN. Over 14 years.

Mr. MATHEWS. Over 14 years.

Mr. STURDIVAN. Yes; my entire Federal service.

Mr. MATHEWS. Mr. Sturdivan, has your laboratory ever conducted any experiments or studies on the characteristics of the Mannlicher-Carcano rifle and the 6.5 millimeter bullet?

Mr. STURDIVAN. Yes; in 1964, we performed tests at the request of the Warren Commission in connection with their investigation into the assassination of President Kennedy.

Mr. MATHEWS. And what type of tests did you perform?

Mr. STURDIVAN. Well, we did air retardation, retardation in a gelatin tissue simulant, tests of cadaver wrists, some skulls, and into some anesthetized animals.

Mr. MATHEWS. Why don't we try this. Before we attempt to get into testimony that will bear directly on the assassination of President John F. Kennedy, why don't we attempt to explain the terminology and methodology that is utilized in the wound ballistic field.

For that purpose, could we have the bullet brought up to Mr. Sturdivan, the bullet and the cartridge?

When you use those two devices for your explanation, let's assume that the cartridge is in the chamber; the bullet is detonated. What happens then? Explain by holding up one of those exhibits and explain precisely what happens from the moment the bullet is detonated.

Mr. STURDIVAN. The bullet begins to move down the barrel of the rifle. As it does, it engages the grooves and the raised areas between the grooves of the rifle, which are called lands, which impart a spin to the bullet. This spin is 1 turn in 8 to 14 inches, depending on the characteristics.

Mr. MATHEWS. Why is the spin necessary?

Mr. STURDIVAN. The spin is necessary to give it stability in the air, stability like a spinning top, a child's top, which will stand on its end while spinning. This is called gyroscopic stability. Now, as the bullet emerges from the end of the rifle, the hot expanding gases that have been pushing it down the barrel are then free to expand. As those gases expand, they move past the bullet creating a temporary instability in the bullet much like tapping the side of the spinning top.

As that happens, the bullet begins to go through a gyrating, wobbling motion where its yaw increases, yaw being the angle of the bullet measured with its line of flight. It bobs in and comes back and then out again in what we call an epicyclic motion.

The bullet, of course, has been designed to be stable and, therefore, this yawing motion, this wobbling motion, damps out very quickly so that, oh, at less than 100 meters, it will approach a very, very small yaw and sit spinning for the next 200 or 300 meters.

Mr. MATHEWS. Will that yaw have any effect at all on the velocity of the bullet as it goes through the air?

Mr. STURDIVAN. Only in a negative manner. If the yaw is excessive, the drag will be excessive. The loss of velocity will be excessive and that is the reason most bullets are designed to fly at very low yaw.

Of course, far down range, several hundred meters, the yaw begins to grow. Then the bullet eventually would lose all gyroscopic stability and start tumbling end over end.

Mr. MATHEWS. Now, you said after about 100 meters, I believe, the bullet will begin to stabilize?

Mr. STURDIVAN. Well, it is stable from the moment that it emerges from the muzzle. At about 100 meters it reaches a very low yaw, perhaps less than a degree, in most cases.

Mr. MATHEWS. Does stability have any effect on velocity, as the bullet is flying through the air?

Mr. STURDIVAN. Only in that it affects the yaw.

Mr. MATHEWS. Will you say that the Mannlicher-Carcano 6.5-millimeter bullet, is a stable bullet?

Mr. STURDIVAN. It is a very stable bullet, perhaps one of the most stable bullets that we have ever done experimentation with.

Mr. MATHEWS. And how do you determine the characteristics of bullets in flight? What devices are utilized in your field to determine these characteristics?

Mr. STURDIVAN. Well, we use a number of devices like——

Mr. MATHEWS. Let me at this time, direct your attention to what has already been marked "JFK exhibit F-111."

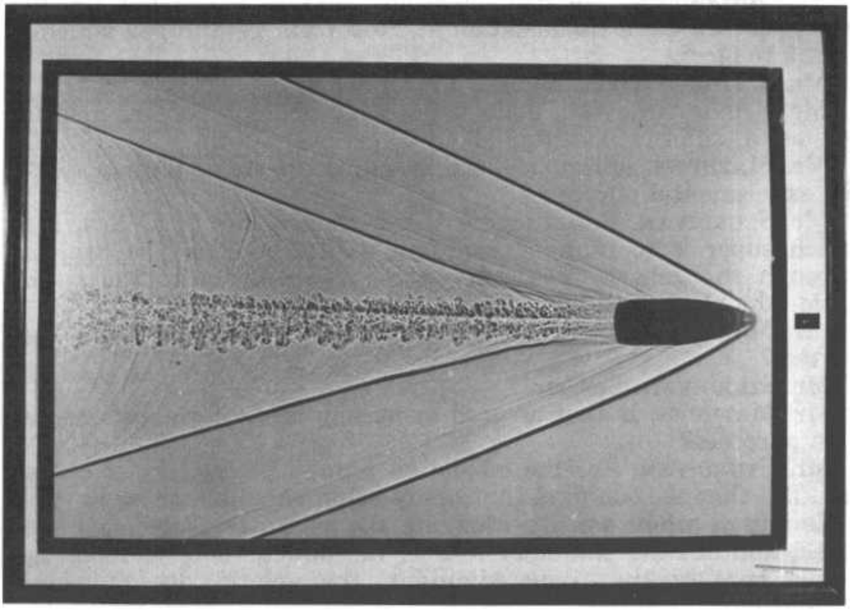
Mr. STURDIVAN. Very well. I will go ahead while they are putting it up.

We sometimes fire through pairs of metallic coated screens which are set so that a chronometer can measure the time between those pairs of screens.

We also take flash shadowgraphs of projectiles. What you have displayed here is a flash shadowgraph of a projectile in the air.

Mr. MATHEWS. Will you describe this exhibit, 111, for the benefit of the committee?

[JFK exhibit F-111 follows:]



JFK EXHIBIT F-111

Mr. STURDIVAN. Very well. This picture was taken by casting a shadow of a bullet on a piece of photographic film obtained from a very short duration flash, such as a spark or an exploding wire. Not only do you see the bullet but you see the turbulent wake of the bullet and the shock wave, the bow wave coming off of the point of the bullet, and the second shock wave coming off of the rarified turbulent wake. This is characteristic of a supersonic bullet.

A subsonic bullet will not cause a shock wave such as this. We will take pictures like this and a shadowgraph of the bullet, for instance. Let's presume that this is the horizontal view. We will take a second view of the bullet from right angles. From this we can measure, from the two angles, the three-dimensional yaw.

We might also have a second shadowgraph taken some few meters down range, so that we can calculate the velocity from the shadows. The exact distance between shadows divided by the time gives us an estimate of the velocity.

Mr. MATHEWS. Fine. Thank you.

Could you now begin to characterize for us the type of devices or materials that are utilized in the study within the wound ballistics field, for example, do you use human cadavers for experimentation in the wound ballistics field?

Mr. STURDIVAN. Not as a matter of course, really. We used cadaver wrists in the 1964 Warren Commission study at the request of the Warren Commission, and dried human skulls that we had obtained from the biological supply houses, but ordinarily we do not use human material; no.

Mr. MATHEWS. What other kind of substances are utilized for experimentation purposes?

Mr. STURDIVAN. We use sometimes animal tissue but for the most part we use a tissue simulant, 20 percent gelatin gel, which is cast into blocks.

Mr. MATHEWS. Gelatin gel, is that like Jello?

Mr. STURDIVAN. Well, Jello is probably about 5 percent gelatin. We use a stiffer composition about 20 percent gelatin.

Mr. MATHEWS. Is that as good as human parts or human tissue for experimental purposes?

Mr. STURDIVAN. For studying the characteristics of bullets, it is much superior to human or animal tissue because you can see through the gelatin. You can watch the behavior of the bullet inside the block with high-speed movies.

Mr. MATHEWS. You indicate you also use animal tissue, is that correct?

Mr. STURDIVAN. Yes, sir.

Mr. MATHEWS. Is that as good as human tissue for experimentation purposes?

Mr. STURDIVAN. For the effects on human beings, no, of course not. But then we don't get that many volunteers. [Laughter.]

Seriously, when we are studying the characteristics of tissues itself, and not the characteristics of the bullet, then we must use tissue because the tissue simulant, the gelatin doesn't bleed, doesn't have nerves or vessels. Animal tissue in general is not that different from human tissue in its characteristics, density, conductivity of the nerves and so forth.

Mr. MATHEWS. Mr. Sturdivan, let's make a couple of assumptions. Let's assume a gelatin block is set up, the rifle is fired, the bullet penetrates a more solid mass than air, what happens then and describe for us the effects on velocity, stability, yaw as that bullet goes through a more dense material.

Mr. STURDIVAN. You have to remember that tissue is about 800 times denser than air and, consequently, all of the effects that are caused on the bullet are much magnified. Its drag is increased by 800 times. In fact, it loses its gyroscopic stability, and the yaw immediately begins to grow. As the bullet enters and penetrates the tissue, it will grow to—depending on the bullet—perhaps nearly 180° or even to 270° of yaw. Eventually, the bullet, if it would go continuously through the medium without stopping, would eventually end up moving sideways at 90° or 270°.

Mr. MATHEWS. Could you explain that by utilizing what has been previously marked JFK exhibit F-112, F-113, F-114, F-310, and F-116?

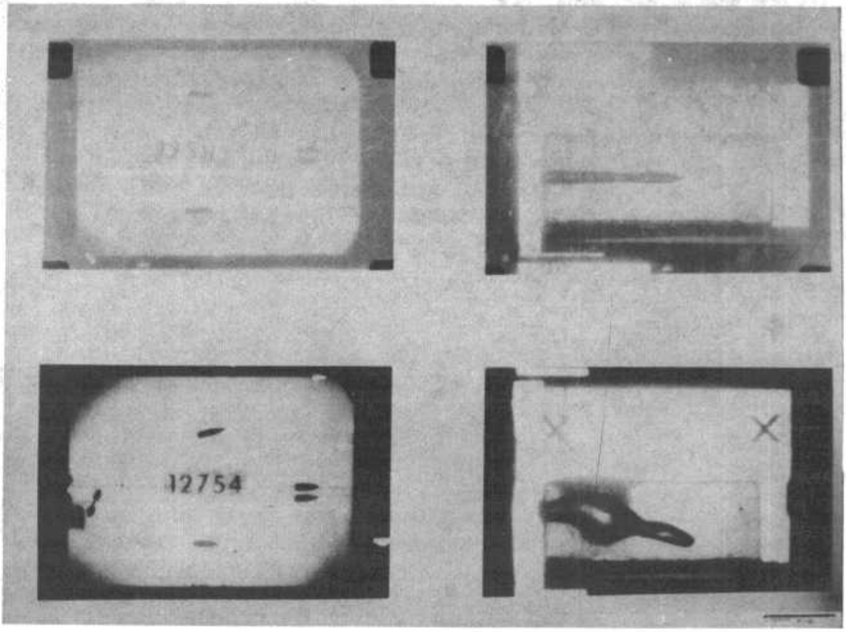
Can you step over?

Mr. STURDIVAN. Very well.

Mr. MATHEWS. Mr. Chairman, could we have JFK exhibits F-112, F-113, F-114, F-310, and F-116 incorporated in the record, please?

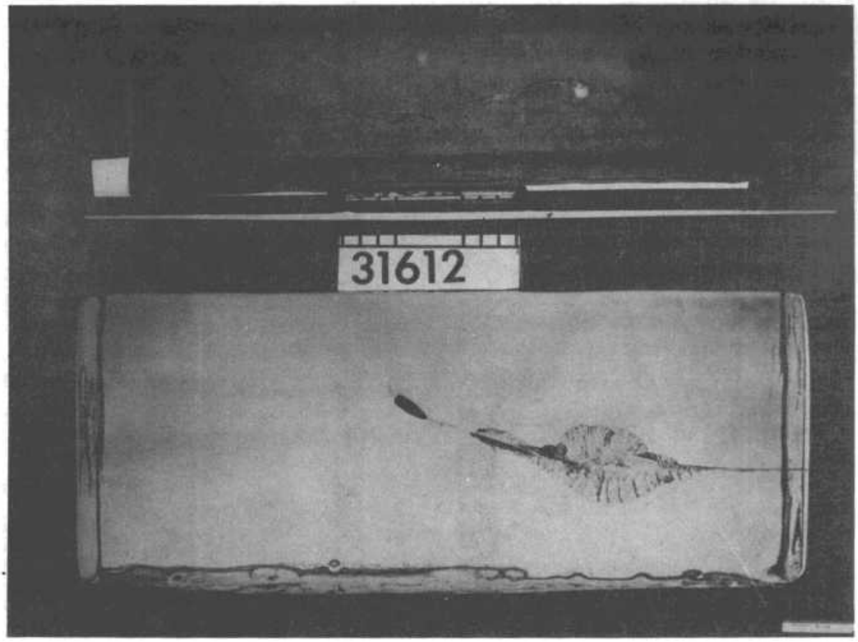
Chairman STOKES. Without objection, they may be incorporated into the record at this point.

[The above referred to JFK exhibits F-112, F-113, F-114, F-310, and F-116 follow:]

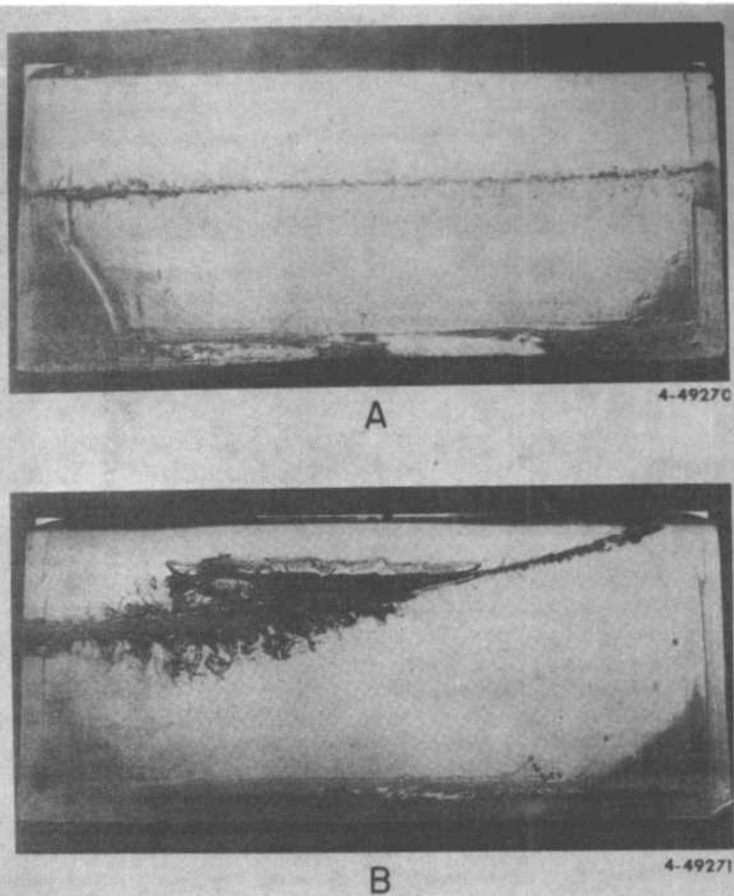


JFK Exhibit F-112

JFK Exhibit F-113



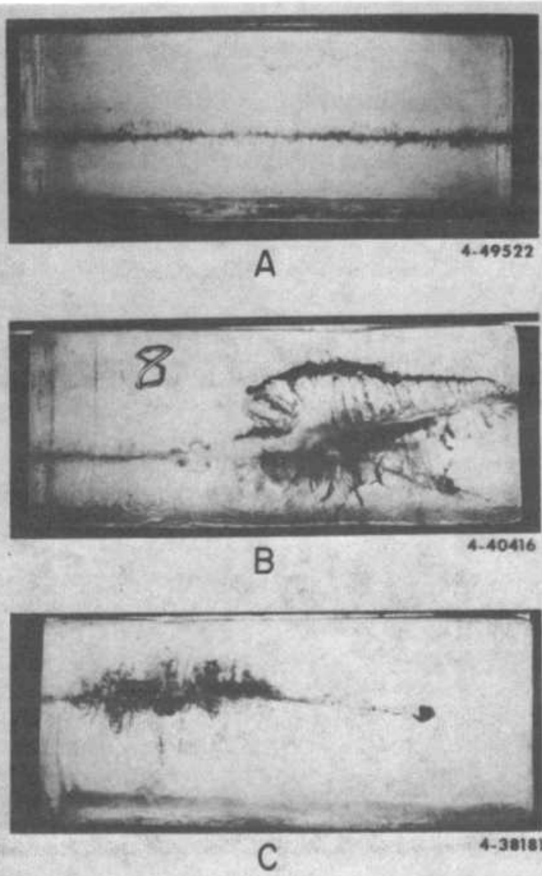
JFK EXHIBIT F-114



PERMANENT TRACTS LEFT BY 6. 5-MM BULLETS IN 20% GELATIN
AFTER PERFORATING RETARDATION TARGETS

A. Tract left by stable bullet
B. Tract left by unstable bullet

JFK Exhibit F-310



PERMANENT CAVITIES LEFT IN GELATIN TISSUE MODELS BY BULLETS

A. 6.5-mm Mannlicher-Carcano ball at 60-yd range
B. 7.62-mm M80 ball at 55-yd range
C. Cal .257 Winchester-Roberts soft-nosed hunting bullet at 55-yd range

JFK Exhibit F-116

Mr. Sturdivan. Starting first with F-112, you see here a spark shadowgraph, a flash X-ray, of a bullet in flight, and this is taken in a 45° angle mirror so that we are getting orthogonal views of the bullet. As you can tell from this, it has very small yaw.

This is a frame of one of the high speed movies that we have taken. It runs approximately 27,000 frames per second, and so effectively stops the bullet in flight. As you can see, the penetration into the gelatin block is very straight, indicating that the yaw is not dramatically increasing at this point.

This is a similar .30-caliber bullet, which is caught in flight and shows a component of yaw in one direction. Of course, the component is missing from the other view. This yawing bullet strikes the gelatin block, and rapidly increases in yaw. The maximum yaw, 90) occurred about here. It goes on through 180° at this narrow pinched in waist and then begins to grow back again and is actually probably moving sideways here at the point where the film ends.

That essentially expresses how the yaw grows. Of course, the velocity of this bullet [indicating unyawed bullet] is much higher because it is not yawed and the drag force is not nearly as great as it was with this bullet [indicating yawed bullet].

We have similar views on exhibit F–113. It shows a view of an M–193 bullet. This is the bullet that is fired from the M–16 rifle that was used extensively in Vietnam. It is a caliber .22 but at a high velocity, approximately 3,000 feet per second.

This bullet entered, and as you can see, it goes nice and straight for a little while. Then the yaw increases dramatically. The pressure is increased dramatically and the bullet begins to fragment, pieces are broken off, the bullet continued, although the track is not clearly visible, from here it continues to exit from the corner of the block.

Mr. MATHEWS. Mr. Sturdivan, could you also speak up, please?

Mr. STURDIVAN. F–114 is the same bullet at a lower velocity. That velocity would be encountered at about 800 meters per second. The lower velocity doesn't make any difference on the way in which the yaw grows. It comes in, the yaw grows, it tumbles then ends up moving backward at the point where it stops.

This bullet, of course, was not deformed because the pressures, due to the lower velocity, were never high enough to deform the bullet.

Mr. MATHEWS. The next exhibit, Mr. Sturdivan, should be F–310 on your left.

Mr. STURDIVAN. F–308.

Mr. MATHEWS. On your left, sir. Let me ask you a question in F–114, why did that bullet enter straight and then yaw upward—right behind you?

Mr. STURDIVAN. The bullet entered straight because it was unyawed in normal flight, and bullets are engineered to be stable and, therefore, it strikes at low yaw. When it is unstable inside the block, naturally unstable inside the block, it yaws dramatically, in every case. All bullets are unstable in tissue, which is 800 times as dense as air.

Mr. MATHEWS. The point being is that all bullets do not go straight when they enter a solid mass.

Mr. STURDIVAN. Oh, no bullet actually goes straight when it enters a solid mass. The lift forces, which are better shown, I think, on——

Mr. MATHEWS. Will you explain exactly what that exhibit is? F–310——

Mr. STURDIVAN. F–310 shows a picture of a Mannlicher-Carcano bullet, which, as I said, was one of the most stable bullets we have ever studied. This bullet perforated—the upper bullet perforated 15 inches, 38 centimeters, of gelatin tissue without appreciably increasing in yaw. You see some evidence of it right at the end, the yaw is beginning to increase. This is because it struck stably, even though it had perforated a 4-inch gelatin target ahead of it.

Chairman STOKES. Would you have the witness suspend for a moment until we get the sound system worked out here?

Mr. MATHEWS. Yes, sir.

Chairman STOKES. Mr. Sturdivan, speak a little louder, if you would, please, sir, because members of the committee are having extreme difficulty in hearing you.

Mr. STURDIVAN. I am sorry. Perhaps if I hold the mike up closer to my mouth.

Chairman STOKES. That does help, thank you.

Mr. MATHEWS. As you address yourself to F-310, will you explain precisely what that particular experiment was meant to achieve?

Mr. STURDIVAN. Yes, sir. This is part of the Warren Commission exhibit and the experiment that was done for the Warren Commission. I am not sure whether it was introduced into the evidence or not. This was a firing to the Mannlicher-Carcano bullet, a 6.5 millimeter, through some 13½ centimeters, which is approximately 4-inch gelatin blocks, then through an air space and allowed to strike a second block. This is only two of the examples of several shots that were made.

In the upper view, the bullet struck at very low yaw and kept its stability through the 15 inches. That bullet, after passing through the first target, struck the second target in an unstable or yawed position, then this curving path is what resulted.

The bullet enters, and because the flow of the gelatin around the bullet is not perfectly symetric, it develops a lift, much like an airplane wing, and will deviate from its path, making a curved path through the gelatin. This is evident particularly in F-114 as well. The lift forces cause the bullet to make a curved path through the gelatin.

Mr. MATHEWS. So we say F-310 and F-114 are consistent with the theory that a bullet could enter one man straight, in a straight trajectory, and on exiting that man be curved slightly?

Mr. STURDIVAN. Well, let's put it this way. With most military bullets, like the M-193, the bullet would curve almost immediately because the yaw begins to grow almost immediately. With the Mannlicher-Carcano bullet, it is much more stable, the yaw begins to grow much more slowly, and it curves much more slowly. So that at a target of 4 or 5 inches of soft tissue, that bullet would not deviate appreciably from its path.

In a much longer track, particularly if the bullet were unstable when it struck, it would in fact deviate from its path. It would not go in a straight line.

Mr. MATHEWS. Again, Mr. Sturdivan, in JFK exhibit F-113, which is the second one on your left, what caused the bullet to break up, what factors cause a bullet to deform?

Mr. STURDIVAN. It is the force. The force developed on the bullet exceeded the strength of the bullet and, therefore, it caved in and began to deform.

Mr. MATHEWS. Let me, Mr. Sturdivan, direct your attention to JFK exhibit F-116. Could you describe for the benefit of the committee exactly what experiments were conducted utilizing this particular exhibit?

Mr. STURDIVAN. Very well. The upper one, labeled A, is again a Mannlicher-Carcano bullet, not striking another target previously but striking this as the initial target, and as you can see, it is quite stable all the way through the 15 inches of gelatin.

The block labeled B is an example of a 7.62 millimeter M-80 bullet, which is fired from the M-14 rifle. That is the NATO standard .30 caliber bullet.

As you can see, it was initially stable, it caused a nice clean track, began to yaw, and at approximately 10 inches was at 90 degrees, continued to yaw on past and exited probably something less that 180°.

The third block, labeled the caliber 257 Winchester Roberts, is a normal, typical hunting bullet that has a soft nose. Of course, a hollow point would behave exactly the same. It has a very short stable track, but the bullet begins to expand immediately on impact, and the only reason that it has any short track is that it takes it a finite time to expand into its final deformed condition, and its drag force is much increased as it begins to expand. This is a positive feedback loop.

As it expands, the drag force increases. As the force increases that increases the expansion. So it rapidly expands causing this massive wound track early in the block and then comes to a rest.

This explains the difference between a military bullet and a soft nose hunting bullet. The military bullet being solid depends on its yawing to deform, whereas the hunting bullet will deform immediately.

Mr. MATHEWS. Are you able to predict the drag force on the bullet, scientifically?

Mr. STURDIVAN. Well, yes, for military bullets in particular we are able to predict the drag forces with some precision.

Mr. MATHEWS. And how are you able to do that?

Mr. STURDIVAN. Well, through our mathematical models of the physics of what happens to bullets in gelatin.

Mr. MATHEWS. Let me direct your attention to JFK exhibit F-115. Can you explain briefly for the benefit of the committee how many people in the wound ballistics field are able to predict drag force?

Mr. STURDIVAN. This is a very simple drag force equation, actually attributed to Sir Isaac Newton, the man who invented calculus, also invented ballistics, I guess.

Typically, you might see the drag force as a function of the other variables. The way I have expressed it here, the drag force is divided by the presented area. This gives us the pressure on the bullet, and the units that we would be most familiar with in describing this pressure would be in pounds per square inch. At some level of pressure any material will deform.

So, here is the drag pressure, which is a function of a dimentionless drag coefficient, multiplied by the density of the material that it is flying through, and the square of the velocity.

So, we can see here all of the essential elements that contribute to increasing force. With an increase in density, as I said awhile ago, moving from a very small density in air to 800 times that density in gelatin increases the drag force by 800 times. Moving from a relatively low velocity to a high velocity dramatically increases drag force and pressure.

In fact, the pressure increases much more rapidly than the velocity does because of the square term.

Mr. MATHEWS. So with that formula are you able to predict when the bullet will begin to deform?

Mr. STURDIVAN. To a certain extent; yes. I must point out for the physicists in the audience that this is an oversimplification. The first order effects of drag force are density. There are also viscosity, which is like the friction that is encountered in going through material, that is the second order effect, and the strength of the material is the third order effect. Since I have excluded everything except the density variable these could only be considered rough approximations.

But for a guiding metal jacketed bullet like the Mannlicher-Carcano, as I recall, the yield pressure of this bullet is 3.8 times 10 to the 10th dines per square centimeter, which to most people is absolutely meaningless, but it means the bullet is approximately 4 times the strength of bone.

Mr. MATHEWS. So at what velocity will a bullet begin to deform?

Mr. STURDIVAN. OK, the bullet would begin to deform, if it strikes say, soft tissue, at something—remember, the density of soft tissue is around one, the density of water, and it will begin to deform at something in excess of 2,000 feet per second. In other words, at the muzzle velocity of the Mannlicher-Carcano.

If it strikes bone, which is twice as dense, then it would begin to deform nose on at approximately 1,400 feet per second. If the bullet turns sideways, which is a weaker orientation, it will deform down to around 1,000 feet feet per second.

Mr. MATHEWS. Did you bring along with you today, Mr. Sturdivan, some films to show the committee to demonstrate that precise point?

Mr. STURDIVAN. Yes sir, I did.

Mr. MATHEWS. Could we have about a 1-minute recess in order to set up the projector?

Mr. Chairman, before that, could we have incorporated into the record JFK exhibit F-115?

Chairman STOKES. Without objection, it may be entered into the record at this point.

[The above referred to JFK exhibit F-115 follows:]

$$F/A = C_D \rho V^2$$

Drag Force Formula
Exhibit JFK F-115

JFK EXHIBIT F-115

Mr. FAUNTROY [presiding.] In the opinion of the Chair, we should wait until the members have returned from this vote before showing the film, so we will remain in recess. I will ask that the lights be put back on. Thank you.

[Brief recess.]

Mr. PREYER [presiding]. The committee will come to order, please.

Mr. Mathews, are you ready to proceed? Mr. Mathews, Mr. Sturdivan?

Mr. MATHEWS. We are ready to proceed, Mr. Chairman.

May we have incorporated into the record JFK exhibit F-117, the movie film which will be shown?

Mr. PREYER. Without objection, so ordered.

Mr. MATHEWS. Mr. Sturdivan, will you first explain for the benefit of the committee and the gallery exactly what the film is about to show?

Mr. STURDIVAN. What we are going to see here is a gelatin block being struck by a .30 caliber, that is, a 7.62 millimeter military bullet. It will be coming in from the left, strike the block at approximately 2,800 feet per second. First, I will run the film at approximately 24 frames per second. I will go through and then I will back up and explain frame-by-frame what is happening.

[First film shown.]

This is the first frame that you can see the bullet. It is beginning to penetrate the left-hand side of the block. It travels in a reasonably straight line. The yaw is beginning to increase at this frame, the second frame. The yaw has dramatically increased. You can begin to see the radical velocity of the tissue simulant as it is thrown away from the bullet that is moving through the gelatin.

Many people have called this a shockwave, but the bullet is actually not moving at the speed of sound in gelatin. The speed of sound in gelatin is approximately 5,000 feet per second. This bullet is moving at less than half that velocity. Here the gelatin is being pushed out of the way as the bullet goes through. It has to be very greatly accelerated to be moved out of the way at the instant that the bullet is passing.

That radial velocity is imparted not only to the material that is in contact with the bullet, but everything all the way out to the outside of the block. That radial velocity continues after the bullet has gone.

The bullet has passed, the cavity is still opening up because of that radial velocity. That is not an air-filled cavity, that is a vacuum cavity and because the gelatin is still moving——

Mr. MATHEWS. Pull your mike up, please.

Mr. STURDIVAN. Did I lose my mike again?

Mr. MATHEWS. You have it now.

Mr. STURDIVAN. Because the gelatin is still moving in a radial manner, it continues to move out and the air from outside will move inside the cavity. This is why often they find debris like pieces of clothing, buttons, twigs, dirt, and all sorts of things drawn into wound cavities in combat. That is because the tremendous radial velocity of the gelatin creates the vacuum that pulls the air and the debris in with it.

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Let me run this one on through and we will see a second gelatin block, identical to the first. This is a 6 by 6 inch gelatin block approximately 15 inches long. The second gelatin block which we will see in a moment——

Mr. FAUNTROY. Will the gentleman yield for just a moment? Those last pictures were the pictures of the gelatin after the bullet had left?

Mr. STURDIVAN. Yes.

Mr. FAUNTROY. So, the bullet was not there when all that movement was taking place?

Mr. STURDIVAN. That's right. It was the radial velocity, the tremendous momentum, the radial momentum that was left in the block that caused it to gyrate like that.

Mr. FAUNTROY. Thank you.

Mr. MATHEWS. So, Mr. Sturdivan, that radial velocity created a force, a form of energy within the block itself?

Mr. STURDIVAN. Right, well, the kinetic energy of the bullet was deposited within the block and that kinetic energy is what gives rise to the radial velocity.

Mr. PREYER. Let me ask that the rear door be closed, please, so that we don't have that extra light in the room.

Excuse me, Mr. Mathews.

Mr. STURDIVAN. I will continue with this one. This one is a caliber 223, that is the M-193 bullet from the M-16 rifle again, the Vietnam rifle, traveling at approximately 3,200 feet per second.

Now, this one, as you can see, well, it's much higher velocity. It went in with a reasonably straight path and then tumbled very quickly. The drag force, the pressure, that was exerted on this bullet at that point caused it to breakup. Each of those little points that you can see looks like fingers pointing to the right. Each of those little points is a separate fragment.

Mr. MATHEWS. At what velocity do you think that bullet broke up at?

Mr. STURDIVAN. The bullet broke up at almost its muzzle velocity. The bullet would break up, as I said before, at anything above 1,000 feet per second; well, it would begin to deform at about 1,000 feet per second.

But remember, the higher the volocity is, the higher the forces are and the much more extensive the break up is. In this case, we saw a very high velocity, very high pressure and very extensive breakup.

The major part of the bullet is at the top of the block. As you can see, this block gets a tremendous radial velocity because of the much greater expenditure of energy.

That bullet is just about to leave the top of the block toward the right point. It is very faint, but you can see the bullet or a fragment of the bullet suspended in air above the block right outside the cavity.

Another couple of frames, it is moving at a reasonably low velocity now. It is sitting right at the corner of the fiducial marker above the block, the major fragment of the bullet.

The remaining fragments of the bullet are still within the block. As you can see, the block continues to gyrate. The cavity collapses and then rebounds, opening up slightly again. The bullet, the piece that escaped, is long gone but the block continues to gyrate under the influence of the energy that was deposited in it.

That terminates the first section of the film.

Mr. MATHEWS. Can we have the lights, please? Mr. Sturdivan, will you have your seat, please?

Let me pose a couple of questions about radial velocity. Is that the same as shockwaves?

Mr. STURDIVAN. Oh, no. No, the bullet is moving at subsonic velocities inside the block and the radial velocities are just the reactions of the pressure moving away from the bullet, away from the line of flight. There is momentum in each little piece of gelatin. But, of course, the total momentum is conserved.

Mr. MATHEWS. Mr. Sturdivan, let me direct your attention to JFK exhibits F-273, F-320, and F-294.

[JFK exhibits F-273, F-294, and F-320 were entered previously.]

Mr. Sturdivan, this committee heard testimony yesterday from Dr. Wecht that indicated, in his opinion, that the bullet struck President Kennedy in the skull, or the neck, I should say, the back of the neck. Excuse me, his rear back of his neck, and then passed straight through, which is shown by the exhibit on the left. The question I want to pose to you is this, since you are a scientist and I assume being a scientist, you have a better than average understanding of mathematics. Assume you are a professor in a major college or high school.

If you had a student and he came to you and presented this as evidence of what occurred in Dealey Plaza on November 22, 1963, would you give him an "A" for bringing a piece of scientific analysis or would you give him an "A" for speculation and explain why you will give him an "A" for one or the other.

Mr. STURDIVAN. Well, it is difficult to evaluate just a final drawing. Of course, you would have to go through the mathematical manipulations that went into such an analysis. I would presume that the individual had much more information than we have presently been given; that is, the Zapruder film shows a horizontal view of the President, the Governor and the car and from that view alone, it would be virtually impossible to reconstruct a plan view that is shown here; it is at 90°.

The relative position of the two people would be impossible to determine from that film alone.

Mr. MATHEWS. What other factors would you need to know before constructing that exhibit?

Mr. STURDIVAN. We would have to have the position of the two people, not only their position of their center of mass, which Dr. Wecht indicated yesterday would not change very much in a major part of a second, but you would have to know the exact position of the head, the neck, whether a person was moving at the time, had stopped to look down at something on the floorboard. In other words, the exact position of each occupant of the car would have to be determined from something other than the Zapruder film.

Mr. MATHEWS. We have to know the speed of the automobile, the elevation of the automobile?

Mr. STURDIVAN. The fact that it was going down a slight incline, which was changing.

Mr. MATHEWS. Would the weather have any factor or play any role?

Mr. STURDIVAN. Weather? Probably not, except for the initial velocity of the bullet which happens to be a little higher in warm weather because the cartridge is hotter. But that is masked within the normal variance of the velocity of the bullet, anyway.

Mr. MATHEWS. What would you say, as a scientist, that the probability is of recreating that event?

Mr. STURDIVAN. Well, given sufficient evidence, the probability would be quite high. But then, I am not in a position to state whether there is sufficient evidence to reconstruct such a drawing. Certainly Dr. Wecht didn't give us sufficient information yesterday to allow a reconstruction of this event.

Mr. MATHEWS. Thank you. Do you care to comment on any of the other exhibits?

Mr. STURDIVAN. Now that it is here, perhaps we could go into the relative deformation of the several bullets that are shown on the exhibit to the right. I can't remember the number.

Mr. MATHEWS. I believe that is JFK exhibit F-294.

Mr. STURDIVAN. On F-294, it shows the picture of five bullets. Commission exhibit 399, of course, is the infamous bullet. The commission exhibit 572, as I understand it, were a couple of bullets that were recovered in cotton-waste media, which, incidentally, is a little denser than tissue and, therefore, caused perhaps a little more extensive deformation than a soft recovery in gelatin would have.

Exhibit 853 is a bullet that has ricocheted from the rib of a goat carcass, as Dr. Wecht indicated. However, let's remember that the goat, which is roughly 100 pounds, is much, much smaller than Governor Connally and, therefore, the bullet passed through a relatively small amount of soft tissue before it hit the bone and, therefore, lost correspondingly less velocity.

So, we would have to say that the striking velocity on that bullet, C.E. 853, was much in excess of the striking velocity on Governor Connally, even if the bullet had passed through nothing before it hit Governor Connally.

C.E. 856 is a bullet that was shot directly into a cadaver wrist without passing through anything before it hit. It is characteristic of the kind of deformation that you would expect of a bullet that strikes at high velocity. In other words, this was direct proof that the bullet that struck Governor Connally's wrist was not at high velocity; that is, CE-399 was not at high velocity. Otherwise, it would have been deformed as this bullet was in striking dense bone.

Mr. MATHEWS. Thank you, Mr. Sturdivan.

Let me direct your attention now to JFK exhibits F-255 through F-258, which is frame 313, 14, 15 and 16 of the Zapruder film, and JFK exhibits F-66 and F-53.

The committee has received some evidence to the effect that the second shot that hit President Kennedy entered through the rear of the skull and out the right front.

As you can see from the exhibits, the President's head seemed to have exploded. This explosion has led many people to conclude that the President may have been shot with an exploding bullet or a frangible bullet. By studying these exhibits, could you comment on whether that theory is a possibility?

Mr. STURDIVAN. Literally, an exploding bullet would be a bullet which would have some high explosive incorporated within the structure of the bullet that would be detonated at impact on bone or soft tissue. Such bullets do exist.

A frangible bullet is one that is made to deform very rapidly and, in fact, most of them are made of some sort of matrix with metallic powder inside that matrix. And essentially, I think that you could probably not tell the difference between the skull that had been hit with an exploding bullet, one that had been hit with a frangible bullet or one that had been hit with a hollow point or soft nose hunting bullet or a hard jacketed military bullet that had deformed massively on the skull at impact.

In fact, all of those situations would look, in a film like this which was taken at ordinary speeds, to be very similar.

Mr. MATHEWS. Mr. Sturdivan, taking a look at JFK exhibit F-53, which is an X-ray of President Kennedy's skull, can you give us your opinion as to whether the President may have been hit with an exploding bullet?

Mr. STURDIVAN. Well, this adds considerable amount of evidence to the pictures which were not conclusive. In this enhanced X-ray of the skull, the scattering of the fragments throughout the wound tract are characteristic of a deforming bullet. This bullet could either be a jacketed bullet that had deformed on impact or a soft-nosed or hollow point bullet that was fully jacketed and, therefore, not losing all of its mass.

It is not characteristic of an exploding bullet or frangible bullet because in either of those cases, the fragments would have been much more numerous and much smaller. A very small fragment has very high drag in tissue and consequently, none of those would have penetrated very far.

In those cases, you would definitely have seen a cloud of metallic fragments very near the entrance wound. So, this case is typical of a deforming jacketed bullet leaving fragments along its path as it goes.

Incidentally, those fragments that are left by the bullet are also very small and do not move very far from their initial, from the place where they departed the bullet.

Consequently, they tend to be clustered very closely around the track of the bullet.

Mr. MATHEWS. So, your testimony is you can state for the record that as a result of JFK exhibit F-53, you can state the President was not hit with a frangible bullet or an exploding bullet; is that correct?

Mr. STURDIVAN. That's correct.

Mr. MATHEWS. Again, Mr. Sturdivan, looking at exhibit F-53, can you tell us, based on your expertise in the wound ballistics field, where the approximate track of the bullet that traveled through the President's skull was located?

Mr. STURDIVAN. There is extensive deformation at the top of the skull which indicates that the radial velocity that was imparted to the tissue, broke it open and, therefore, relieved the pressure at the top, well, either to the right or the left, since you can't distinguish on an X-ray.

You would presume, then, that the soft tissue, which was badly damaged, would have moved somewhat in the direction of that relieved pressure and, therefore, would be displaced somewhat upward from the original track. So, I would place the original track as being somewhat lower than that trail of fragments indicated through there; certainly not much lower.

Mr. MATHEWS. So, it is your opinion that it was more likely that the President was shot in the upper portion of the skull as opposed to the lower?

Mr. STURDIVAN. Right, there is no indication of any track in the lower half of the skull. It definitely was in the upper part.

Mr. MATHEWS. Thank you.

Now, Mr. Sturdivan, according to your testimony, the President was not shot with an exploding bullet. What scientific reasons do you have for the fact that his skull exploded?

Mr. STURDIVAN. As we saw in the gelatin blocks, the tremendous radial velocity that is imparted to the tissue, soft tissue, as the bullet goes through, probably in this case having massively been deformed by impact on the skull. The drag force is very high. The radial velocity is high, exerting tremendous pressure on the inside of the skull. And this literally lifts the skull up, fractures it and allows some of the soft material to move between the cracks.

Mr. MATHEWS. Have you ever conducted any experiments which would verify that theory?

Mr. STURDIVAN. Yes; in the 1964 study for the Warren Commission, we did do several studies on skulls.

Mr. MATHEWS. Did you record those studies?

Mr. STURDIVAN. We recorded them in still cameras and also with movies.

Mr. MATHEWS. Do you have that film today?

Mr. STURDIVAN. Yes, I do.

Mr. MATHEWS. Before you show it to the committee, could you explain briefly what they should look for in analyzing this film?

Mr. STURDIVAN. Before the lights go out, the film is of 4 of 10 skulls that were shot at our laboratory with the Mannlicher-Carcano 6.5 millimeter. The bullet will be coming in from the left toward the right. The skulls have been filled with gelatin and coated with gelatin in the semblance of the subcutaneous tissue under the scalp. At the point of impact, there's a piece of goat skin with hair intact which simulates the scalp and the hair of the possible victim.

The movies were taken at approximately 2,200 pictures per second. Since the projectile is moving at roughly 2,000 feet per second, we could expect a motion of about 12 inches, 12 to 14 inches between frames as the bullet comes in.

Mr. FAUNTROY. Will the gentleman yield? As you prepare to show the movie, is it my understanding that you used the Mannlicher-Carcano rifle that was found on the sixth floor of the Texas School Book Depository Building or was this another rifle?

Mr. STURDIVAN. Well, sir, we had two rifles. Both of them were used fairly extensively, but we did not want to over-use the Oswald rifle because of the wear and the change of the characteristics. So, I cannot state for a certainty which of these were shot with which rifle. But, some of them were shot with the Oswald rifle and some with the other rifle.

Mr. MATHEWS. Thank you.

Mr. Chairman, may we have JFK exhibits F-304 and F-305, the movie films which will be shown, entered in the record?

Mr. PREYER. Without objection, so ordered.

[Showing of second film.]

Mr. STURDIVAN. There is another section of film here, before we get to the skulls, which we forgot to mention. Perhaps we should go ahead and go through it since it is already there. This is a can of tomatoes which I think demonstrates some of the principles of physics that are involved here.

The picture will be much the same as those with the skull. The bullet will be coming in from the left, will strike the can and you will see pieces of the can moving toward the right in the direction of the bullet, but you will also see pieces of the can moving in other directions. Notably, the top of the can will be moving back toward the left in the direction from which the bullet came.

You notice the backsplash as the bullet has entered the left-hand side of the can. The material is beginning to move back out. This is called the backsplash of the projectile.

In the next case, the bullet is still within the can and, in fact, has stopped within the can.

Mr. MATHEWS. Was that a 6.5 millimeter?

Mr. STURDIVAN. No; this was some other bullet. I am not sure what the identity of the bullet was. It is probably a caliber .22.

I apologize for the darkness of these films, but this will begin the skull sequence. The first one is light so let me run right through it. You will see what happens to the skull taken at high-speed movies.

Mr. MATHEWS. Could you explain, first, the skull itself, the composition?

Mr. STURDIVAN. The skull was, as I said, the dried skull, obtained from a biological supply house, was filled with gelatin tissue simulant and the shiny effect on the outside is a coating of gelatin on the outside of the skull. To the left is a piece of goat skin simulating the scalp and hair. I will run right through the first one which is rather dramatic, and I will stop action on the second skull [describing second skull impact].

The bullet has come in from the left, has impacted the skull through the scalp simulant and is now within the skull. As you can see, the radial velocity that is imparted at the first part of the track has begun to crack the back piece of the skull.

This is the very next frame. It shows the fragmented bullet and fragments of the skull being blown away from the front of the skull.

Mr. MATHEWS. The bullet is gone now; is that correct?

Mr. STURDIVAN. Pieces of the bullet have exited the skull. It is hard to tell whether they have actually gone out of the frame or whether they may be incorporated into that white mass which is mostly bone with a little bit of gelatin tissue simulant in it.

As you can see, the radial velocity has already begun to fracture the skull extensively along and across suture lines.

As you can see, each of the two skulls that we have observed so far have moved in the direction of the bullet. In other words, both of them have been given some momentum in the direction that the bullet was going. This third one also shows momentum in the direction that the bullet was going, showing that the head of the President would probably go with the bullet.

This is amplified, however, in these skulls because they are not tied to a human body. They are free to move from the table.

Also, you will see that as the skull goes forward, some of the material of the skull and the contents were blown out toward us. Consequently, the opposing momentum carries the skull away from us, rotates it away from us so that we can actually see the bottom part of the skull in this shot. In fact, all 10 of the skulls that we shot did essentially the same thing. They gained a little bit of momentum consistent with one or a little better foot-per-second velocity that would have been imparted by the bullet and they also lost material toward us, that is, toward its right and, therefore, rotated toward its left.

That terminates that sequence of film.

Mr. MATHEWS. Could we have the lights, please?

I have one final question for you, Mr. Sturdivan, and in answering that question, let me direct your attention to JFK exhibits F-307 and F-306.

Mr. Sturdivan, as you can see of JFK exhibit F-307, which is on my left, the hole location is approximately in the top of the President's skull. As you can see from exhibit F-306, the hole location is at the bottom of the President's skull. F-306 is a skull that was utilized by Edgewood Laboratories for their experiments for the Warren Commission; is that not so?

Mr. STURDIVAN. Yes, it was, that is one of the skulls, probably one of the skulls we saw in the film sequence.

Mr. MATHEWS. My question is this: Would the location of the hole in the President's skull make any change in your testimony as to the explosive effect that occurred within the skull?

Mr. STURDIVAN. Oh, no. Once the bullet enters the soft material within the skull, the radial velocity is imparted and the effect is exactly the same no matter at what point it enters.

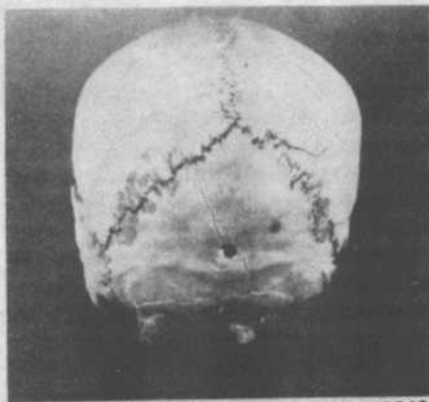
The only effect might be in which portion of the skull was actually blown out. In other words, it might blow out a little higher and a little more toward the top if the bullet entered a little more toward the top rather than blowing out on the side as is indicated in the second exhibit.

Mr. MATHEWS. Mr. Chairman, could we have exhibits F-306 and F-307 incorporated in the record? In addition, could we have F-111 and F-255, F-256, F-257, and F-258 incorporated in the record, please?

Chairman STOKES [presiding]. Without objection, they may be entered into the record at this point.

[JFK exhibits F-111, and F-255 through F-258 were entered previously.]

[The above-referred-to exhibits, JFK exhibits F-306 and F-307 follow:]



4-49542

A

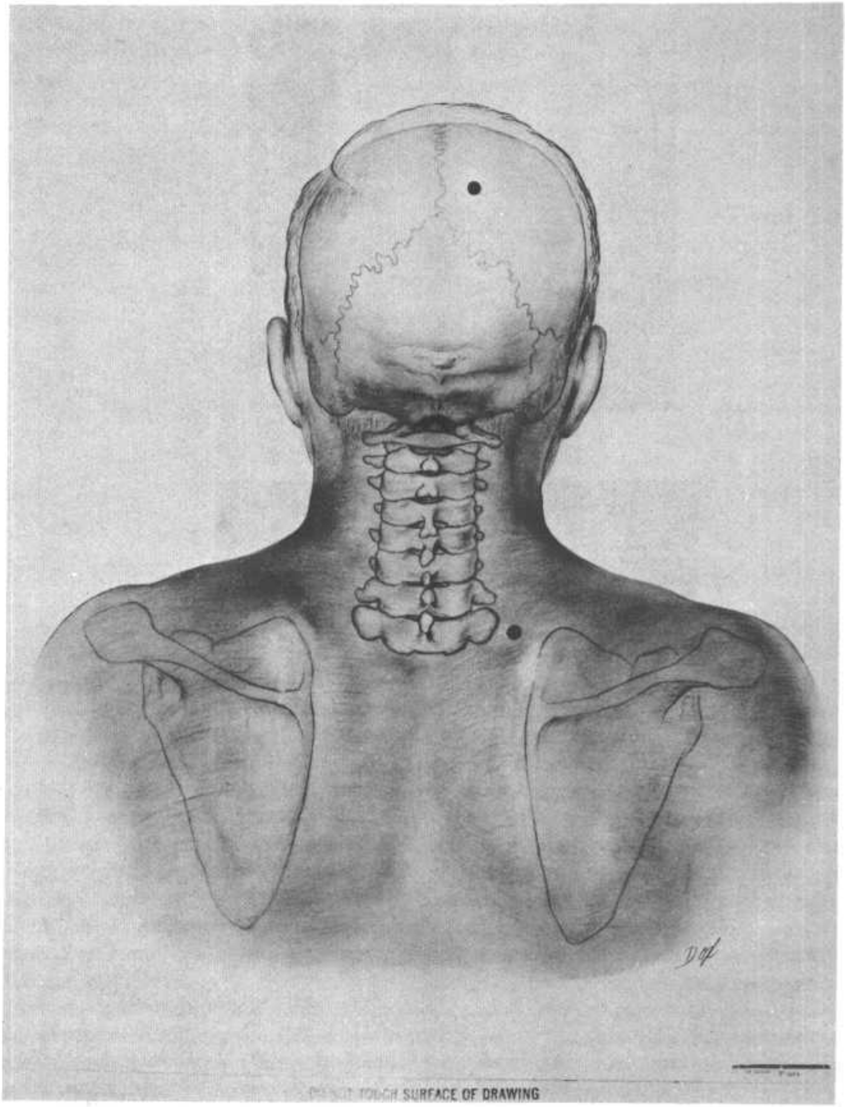
4-49539

B

SKULL DAMAGE PRODUCED BY THE 6.5-MM MANNLICHER-CARCANO BULLET AT 90-YD RANGE

A. Entrance wound
B. Exit wound

JFK EXHIBIT F-306



JFK Exhibit F-307

Mr. Mathews. Also, Mr. Chairman, I have no further questions of this witness.

Chairman Stokes. The Chair will first recognize the gentleman from the District of Columbia, Mr. Fauntroy, for as much time as he may consume, after which the committee will go to the 5-minute rule.

The gentleman from the District of Columbia, Mr. Fauntroy.

Mr. Fauntroy. Thank you, Mr. Chairman, and thank you, Mr. Sturdivan, on behalf of the nonphysicists on the panel and in the country. You have goven us, I think, an adequate introduction to wound ballistics and the science of the effects of bullets on the human body.

I think I am fairly familiar now with things like yaw and velocity and drag and trajectory and stability. But I think I am more interested in having you to help us with some hypotheticals relative to the subject of this investigation, and for this purpose, I would like to place in view JFK exhibits Nos. F-113 and F-116 and F-81. As they are being placed there, Mr. Sturdivan, I would like to have you analyze with us a few hypotheticals.

Let's assume three things. First, the rifle is a Mannlicher-Carcano of the kind found on the sixth floor of the Book Depository. We have that rifle here. You might want to just lift it for us. Let's assume that is the first.

Second, the bullet is a 6.5-millimeter bullet, and, third, the shot came from the sixth floor of the Texas Book Depository Building. What would be the striking velocity of a 6.5-millimeter bullet fired from the building and hitting a man in the upper right back?

Mr. STURDIVAN. Well, the muzzle velocity of this bullet varies between 2,000 and 2,200 feet per second. It will have lost some velocity in traversing some distance. Say at 100 yards it would have about 1,800-feet-per-second velocity. One hundred yards was roughly, I think, the distance we are talking about here. So that would be 1,800 feet per second.

Mr. FAUNTROY. And that is the velocity at which it would probably have hit a body from the distance that we know is from the sixth floor to where the President was at the time that his body was struck?

Mr. STURDIVAN. Yes, sir.

Mr. FAUNTROY. Could the bullet have gone through his neck at that time?

Mr. STURDIVAN. Oh, yes; this bullet if only encountering a few inches of soft tissue would go through losing almost no velocity, 100 feet per second or thereabouts.

Mr. FAUNTROY. So that while it was fired when it left the muzzle, it would have been over 2,000 feet, by the time it hit it would have been about 1,800 feet per second?

Mr. STURDIVAN. Yes.

Mr. FAUNTROY. And exiting the body, not striking any bone?

Mr. STURDIVAN. Without striking any bone.

Mr. FAUNTROY. Striking flesh it would have lost another what?

Mr. STURDIVAN. One hundred feet per second or so. Being a little less than maybe 1,700 feet per second at that point.

Chairman STOKES. Would the gentleman yield?

Mr. FAUNTROY. I would be very happy to.

Chairman STOKES. Was there something the gentleman wanted done with the rifle?

Mr. FAUNTROY. No, you can put that back, please.

Now, once the bullet exited the neck, having gone through the flesh, what would have been the condition of the bullet?

Mr. STURDIVAN. Well, it would have been given some—as I stated earlier, the bullet is unstable in tissue, the yaw begins to grow, with a Mannlicher-Carcano this growth of yaw is relatively mild, but it would have been given a little bit of angular momentum, so it would come out at some yaw, an increasing yaw. Of course, as it came into the air, it would be again in a low-density medium and therefore would tend to stabilize out again, so the yaw that was imparted would begin to damp out.

Mr. FAUNTROY. So it would yaw a little coming through but would be pretty much straight?

Mr. STURDIVAN. It is still very straight but its angular momentum is such that as it comes out it is turning.

Mr. FAUNTROY. I see.

Mr. STURDIVAN. OK.

Mr. FAUNTROY. Could it have struck another man sitting directly in front of the first man?

Mr. STURDIVAN. If the initial trajectory had been into that man, yes, because it would not have deviated significantly from its original trajectory.

Mr. FAUNTROY. What would have been the nature of the entrance hole in the second body after passing through the first?

Mr. STURDIVAN. OK, if you will recall, I said that the bullet takes a bobbing motion. It has some yaw and then it decreases almost to zero yaw, then it goes back up again. It depends on exactly what orientation it had at the moment of striking the next body as to what the entry hole would be like. It could be perfectly round, if the yaw were nearly zero, or it could be elongated, if the bullet were yawing at that point.

Mr. FAUNTROY. Did you conduct any experiments to determine how much yaw a 6.5 millimeter coming through a mass like that which was the neck of the President had and, therefore, what kind of angle it would have hit another body?

Mr. STURDIVAN. Well, we did get imprints on the velocity screens between the first target and the second target, which I showed a moment ago. And on those screens we saw about an equal proportion of round holes and elongated holes, indicating that the bullet was bobbing in and out and it was striking at random orientation into those screens.

Mr. FAUNTROY. All right, now, the bullet passes through the second body, and, say, nicking a rib, and having entered, you say, on a yaw—I guess that is the proper way to put it—slightly angular—having pushed through that way. What would be the nature of its velocity, having left the body as we are theorizing here, just below the nipple—what would have been the condition of the bullet?

Mr. STURDIVAN. OK, our predictive equations apply only to soft tissue, and so consequently I wasn't able to predict what this composite of soft tissue and bone would really have done. Consequently, I would have to rely on the experiments that we did in 1964, shooting glancing blows off of rib—the ribs of goat carcasses, and then scaled those effects up to a much larger man, like the size of Governor Connally.

Now, with the 250-plus-foot-per-second loss in the goat, that would scale up to perhaps a 400-foot-per-second loss in the Governor, given that the bullet entered at normal obliquity, that is, without yaw. It would have, of course, been somewhat higher than that, had it hit in a yawed orientation; Some 400-foot-per-second-plus of loss.

Mr. FAUNTROY. The bullet left the gun at 2,000 feet. Do you think at the point it would have struck the first body it was going at about 1,700?

Mr. STURDIVAN. 1,700 to 1,800.

Mr. FAUNTROY. Feet. It would have lost how much going through, you said?

Mr. STURDIVAN. About a 100. So it is after going through it is perhaps 1,700 feet per second, or a little less, at striking the second body. There it would lose another 400-plus feet per second and exited, say, somewhere between 1,100 and 1,300 feet per second, roughly.

Mr. FAUNTROY. That is velocity at which it is moving?

Mr. STURDIVAN. At the exit of the second target.

Mr. FAUNTROY. Would that be enough velocity to shatter a wrist bone?

Mr. STURDIVAN. Oh, yes. My calculations, rough calculations have shown that when striking the bone it would comminute the bone at anything above about 700 feet per second. So it still has nearly twice that velocity and certainly it would have enough to comminute a bone.

Mr. FAUNTROY. And lodge in the left thigh?

Mr. STURDIVAN. Well, yes; after going through the bone it would, of course, again have lost a considerable amount of velocity, but there is no reason to believe that it would not have enough remaining velocity to penetrate some more soft tissue, although it probably would not have had much in excess of 700, perhaps even less than that. So it probably would not have fractured another bone. In other words, if it had continued on the same path and struck the thick bone it would not have fractured it, it would have stopped.

Mr. FAUNTROY. Let's go back to the starting point, say, of a second hypothetical, that is, let's assume that a second bullet fired from approximately the same position, using the same rifle and bullet, is on its way, and it hits the second man, in the same place in the back, without striking the first man.

Mr. STURDIVAN. Yes, sir.

Mr. FAUNTROY. What would be the striking velocity there?

Mr. STURDIVAN. Well, it wouldn't really be that much higher than it would have been striking the first target. Striking the second target it is 1,800 feet per second. That is, striking the second target without striking the first.

OK. I see puzzlement, let me recapitulate.

In the first case, your first hypothetical, the striking velocity on the first target was around 1,800 feet per second. If it missed the first target it would have essentially the same striking velocity when it hit the second target, which is to say about 1,800 feet per second.

Now, the difference in the striking velocity, having gone through the first target or not having gone through the first target, would make essentially no difference in our predicted behavior in the second target. There are too many other variables; the amount of bone that it actually contacted, whether it contacted the bone directly or whether it hit it a grazing blow, or whether the bullet actually missed the bone, and if that extensive cavity fractured the bone, would make a considerable difference in the remaining velocity of the bullet.

So to boil it all down, the effect in the second target, which would represent Governor Connally, would be almost indistinguishable in the two cases.

Mr. FAUNTROY. How about the entry wound, what would be the nature of that if it were directly?

Mr. STURDIVAN. Well, there is a fairly good probability that that entry wound would be elongated if it had went through another target before—it probably would have been elongated.

Mr. FAUNTROY. That is, it may have gone that way rather than that way [demonstrating]?

Mr. STURDIVAN. Yes, sir.

Mr. FAUNTROY. Is that what you are saying?

Mr. STURDIVAN. Yes.

Mr. FAUNTROY. If it went directly there first, is it likely that you could have gotten that same effect?

Mr. STURDIVAN. Oh, no. If it had struck without having previously encountered another target, it would never have been elongated. This bullet is too stable. It would have had to be a nice round hole, presuming that it struck reasonably normally to the surface.

Mr. FAUNTROY. I will have to review, I can't recall, staff will bring me up to date on whether or not that entry wound was—it was a round hole, all right.

Again, in our second hypothetical question, assuming this bullet traveled at a downward trajectory and exited below the right nipple, smashing into the right wrist and then into the left thigh, would the exit velocity have been greater in the first hypothetical, where it goes through two bodies, or in the second, and what difference, if any, would that have made in the nature of the wrist wound?

Mr. STURDIVAN. Well, in the second case, where it struck without having struck a previous target, the entry velocity would be somewhat higher, but depending on the exact effect on the bone, the amount of deformation and so forth, it might well have been deformed a little more because it struck the rib at a little higher velocity and, therefore, it would have had a little higher drag after having gone through the rib, consequently the exit velocity would probably not have been much different and the effect on the wrist would probably have not been much different.

Mr. FAUNTROY. How much damage would have been done to the bullet in the first hypothetical, as compared with the second, going through two and going through one?

Mr. STURDIVAN. Well, because it had traversed a little less soft tissue before striking the bone it might have struck the rib at a little higher velocity and therefore have been a little more deformed in the second case.

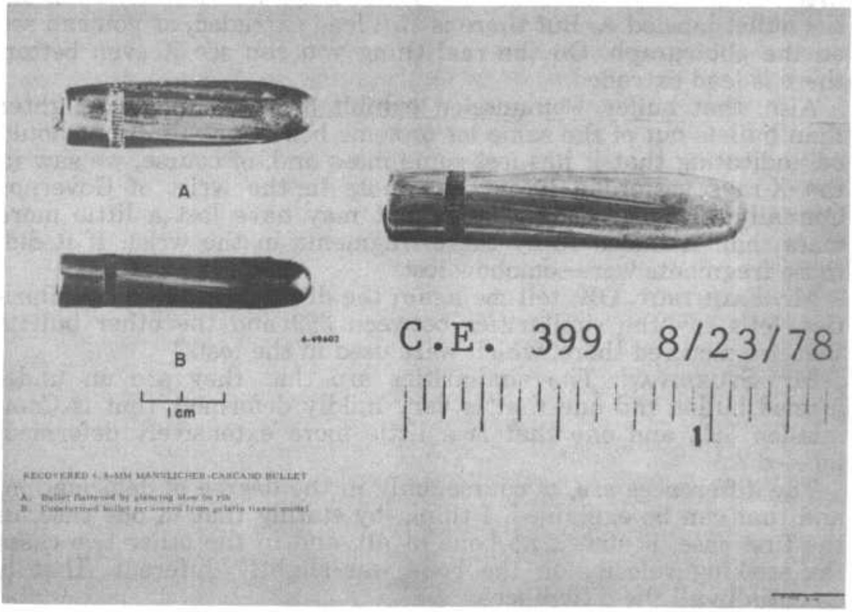
Mr. FAUNTROY. In the first case, therefore——

Mr. STURDIVAN. In the first case less deformation to the bullet.

Mr. FAUNTROY. Mr. Sturdivan, I would like to direct your attention to JFK exhibit F-118. There are blowups—the one on the right—blowups of two 6.5-millimeter bullets, and a blowup of what is now familiar to you as Commission exhibit 399, the bullet believed to have been the bullet that went through the body of both President Kennedy and Governor Connally.

You have done some experiments with those bullets, have you not?

[JFK exhibit F-118 follows:]



JFK Exhibit F-118

Mr. Sturdivan. Yes sir. In exhibit 118, the two bullets on the left were experimental bullets that were fired at Edgewood Arsenal. The one labeled B went through approximately 30 inches of gelatin and was soft recovered, and if one were to apply the word to a bullet, this would be pristine bullet, perhaps the only one that we have seen so far.

The bullet labeled A was one of those which was fired into the carcass of a goat and glanced off the rib. You can't see quite so clearly as you could on the original bullet, but there is some lead extruded from the tail of that bullet, it is flattened and lead has been squeezed out, much like toothpaste out of a tube.

Mr. Fauntroy. That has troubled me. Why does that happen? In some of them I notice it doesn't happen, you don't have that toothpaste effect. Why is that on some of the bullets?

Mr. Sturdivan. Well, that is the method of deformation of the bullet. The first thing that happens when the bullet begins to deform is that the jacket is flattened out and the softer lead core is extruded through the only opening, that is, the opening in the base, like toothpaste out of a tube.

As the bullet continues to react to the pressure, to deform further, it gets much flatter and more lead is extruded. If the pressures are higher than that, the bullet might begin to break up, pieces of the jacket to peel off, or the bullet to break along the cannelure lines you see in the photograph into two or more pieces. What we see here is the first stage of the deformation of a bullet, mild squeezing of the jacket with some extrusion of lead through the tail.

In Commission exhibit 399 we see less flattening, which would indicate that it struck bone at a somewhat lower velocity than did the bullet labeled A. But there is still lead extruded, as you can see on the photograph. On the real thing you can see it even better, there is lead extruded.

Also, that bullet, Commission exhibit 399, is somewhat lighter than bullets out of the same lot or some box of ammunition should be, indicating that it has lost some mass and, of course, we saw in the X-rays yesterday it did lose mass in the wrist of Governor Connally, although in my opinion it may have lost a little more mass than is indicated by those fragments in the wrist. If it did, those fragments were somehow lost.

Mr. FAUNTROY. OK, tell me again the differences or the similarities, let's say the similarities between 399 and the other bullets that are pictured there, which were used in the tests?

Mr. STURDIVAN. The similarities are that they are an undeformed bullet and one that is very mildly deformed, that is Commission 399, and one that is a little more extensively deformed, labeled A.

The differences are, of course, only in the degree of deformation, and that can be explained, I think, by stating that in one case, in the first case, it struck no bone at all, and in the other two cases the striking velocity on the bone was slightly different. That is essentially all the differences.

Mr. FAUNTROY. Mr. Sturdivan, based on your professional experiments conducted by your laboratory, is it possible, in your opinion, for a single 6.5-millimeter bullet to inflict the injuries that were found on the neck of the President and on the torso, wrist, and thigh of Governor Connally?

Mr. STURDIVAN. Yes, sir; it is quite possible that one bullet could have done all of that damage.

Mr. FAUNTROY. Mr. Chairman, I think I will yield at this time to other members who may have questions. I would like to have those exhibits, if they have not already been entered into the record, to be entered at this time.

I have been reminded there is another film that I want to look at, and I don't want to look at, but I think perhaps we had better do it, and that is, as you know, Mr. Sturdivan, I have been concerned about what appears to be the backward movement or rearward of President Kennedy at the time that he was hit with the second shot, and as you may recall, Dr. Baden yesterday, at least explained to us why it was the panel of forensic pathologists' view that the bullet which struck President Kennedy in the head came from the rear, due to something that they called beveling.

Mr. STURDIVAN. Yes, sir.

Mr. FAUNTROY. And that gives me some assistance as a layman in understanding why he would come back, but I wonder if you would care to share with us what experiments you have done that suggest that what we see in the film is really reaction to a shot from the rear, and I know that you have done some experiments. I think we ought to share those at this time.

Mr. STURDIVAN. First, I had an exhibit I don't think has been entered into the record. It is the one with the momentum equation. I think that would help with the explanation.

Mr. MATHEWS. That should be JFK exhibit No. F-303.

Mr. STURDIVAN. Again, I don't want to try to snow the panel with a lot of equations. I think it is important here to point out that there is a significant difference between kinetic energy and momentum. As you see on top of this exhibit F-303, the energy, one-half mass times the velocity squared, is an expression of what shall we say, the destructive capability of the projectile, and as we all know from our familiarity with Einstein, that energy is conserved. Also momentum is conserved. But in this case, the conservation of momentum is slightly different from the conservation of energy.

Conservation of momentum is a vector quantity, that is, it has direction. If a projectile were moving along and then struck another object, then both of those objects would move off with exactly the same momentum that the first object had coming in. In other words, the linear momentum, the product of the mass and velocity, is conserved and the direction is conserved.

Let's apply both of these to a hypothetical bullet that is striking a head and losing some velocity.

Now, the next line labeled momentum lost, all I have done is taken the product of the mass—this is 162 grains divided by 7,000—which gives us the mass of the bullet in pounds. Multiply that mass of bullet in pounds times 800 feet per second, the velocity lost, and we have a quantity, an unusual quantity, 18.4 pound feet per second of momentum which has been deposited by the bullet.

Now, in the head of the President—and I am only giving you a very rough figure here—we take that momentum, 18.4 and divide by the mass of the head, which I have guessed at as being about 15 pounds, which would produce a net velocity of 1.2 feet per second in the head.

This is consistent with the velocity that we saw in the skull films, 1.2 feet per second. That is the velocity of a rapid nod. It is not a tremendous velocity.

Mr. FAUNTROY. Let's try it this way. Let me have JFK exhibit Nos. F-255 to F-258, which are frames 313, 314, 315, and 316 of the Zapruder film. Put those four up for me, and while that is being done, Mr. Chairman, I would like to put JFK exhibit No. F-303 in the record.

Chairman STOKES. Without objection, it may be entered into the record at this point.

[The above referred to JFK exhibit No. F-303 follows:]

ENERGY $= \frac{1}{2} MV^2$

MOMENTUM $= MV$

MANNLICHER CARCANO BULLET

MOMENTUM LOST: $\frac{162}{7000} \times 800 = 18.4$ LB. FT./SEC.

HEAD OF KENNEDY—

VELOCITY GAINED: $\frac{18.4}{15} = 1.2$ FT./SEC.

ENERGY DEPOSITED: 1100 JOULES $\approx$ 800 FT. LB.

Exhibit JFK F-303

JFK EXHIBIT F-303

Mr. FAUNTROY. The exhibits which are being placed show, as I say, a rearward thrust of the President's head and his upper body, a fraction of a second after he was shot in the head, and the assassination critics have insisted this rearward thrust clearly indicates that the shot came from the front, the theory being that the force and momentum of the bullet, Mr. Sturdivan, carried the President's head toward the rear of the limousine.

Mr. STURDIVAN. As we can see from the chart, this velocity of 1.2 feet per second is not the kind of velocity that would throw the President bodily around backwards, forwards, or in any direction no matter which direction the bullet came from. The deposit of momentum from the bullet is not sufficient to cause any dramatic movement in any direction. It would have a very slight movement, assuming that the bullet hit him in the back of the head. It would have a slight movement toward the front, which would very rapidly be damped by the connection of the neck with the body.

In other words, the head would begin to move and then the body would be dragged forward with it at a much lower velocity. Certainly not a very large velocity. Not throwing anybody anywhere.

In fact, I conclude from these films that, since the President does have motion, that it must have arisen from another source, that is, it could not have been the momentum of the bullet.

Mr. FAUNTROY. Have you done any experiments to illustrate to us what you are saying to us?

Mr. STURDIVAN. Yes, we have. It is some archival film that I dug out of our film library back at the laboratory. There was some film taken years ago, and let me explain before we go into the film what is going to happen, what it is.

What I interpret this as is a neuromuscular reaction.

Mr. FAUNTROY. That is the President moving back——

Mr. STURDIVAN. The President's motion is a neuromuscular reaction. Nerves are stimulated by other nerves, by electricity, by chemical means, or they can also be stimulated by mechanical means, and we have all had experiences with that when you bang your crazy bone, you get a stimulus of the nerves, a motion sometimes, sometimes a partial paralysis for a little while. This is mechanical stimulation of the nerves.

This mechanical stimulation, once it starts to move down the nerve, looks exactly the same as any other nerve impulse does. And if this mechanical stimulation is in a motor nerve, that is, one that moves muscles, then the muscle will move.

Now, the extreme radial velocity imported to the matter in the President's head, the brain tissue, caused mechanical movement of essentially everything inside the skull, including where the cord went through the foramen magnum, that is, the hole that leads out of the skull down the spinal cord.

Motion there, I believe, caused mechanical stimulation of the motor nerves of the President, and since all motor nerves were stimulated at the same time, then every muscle in the body would be activated at the same time.

Now, in an arm, for instance, this would have activated the biceps muscle but it would have also activated the triceps muscle, which being more powerful, would have straightened the arm out. With leg muscles, the large muscles in the back of the leg, are more powerful than those in the front and, therefore, the leg would move backward. The muscles in the back of the trunk are much stronger than the abdominals and, therefore, the body would arch backward. The same phenomena has been observed many times by hunters in the Southwest where I came from. Some members of the committee may very well have some experience with shooting jackrabbits.

Mr. FAUNTROY. Shooting jackrabbits?

Mr. STURDIVAN. Yes, sir. Occasionally you will see a jackrabbit sitting. He is hunched down on his back legs which, being the powerful running muscles, are like sitting on coiled springs. When the jackrabbit is shot through the head every muscle is stimulated, those powerful running muscles overpower everything and the jackrabbit springs into the air.

Obviously his motion upward is not as a result of forward momentum of the bullet. Other hunters may have observed the same thing in other animals.

So what we have in the film is a dramatic example taken at 2,200 feet per second of a goat, a live goat, being shot through the head, with a bullet. This is essentially the same technique of euthanasia, that they use in slaughterhouses. In other words a projectile is shot into the brain and the animal is dead essentially at the time the bullet hits, but the nerves and the muscles which are still alive, and very much capable of response, show a dramatic response of this neuromuscular stimulation. So if you are ready we can go to the film.

Mr. FAUNTROY. Let's illustrate that.

Chairman STOKES. If the gentleman would yield.

Mr. FAUNTROY. I would be happy to yield to the chairman.

Chairman STOKES. Prior to the production, the Chair wants to engage counsel for the committee, Mr. Mathews, in a colloquy relative to the film prior to its being shown. Will the counsel advise the committee as to the source from which you procured this film?

Mr. MATHEWS. These films were procured, Mr. Chairman, from Edgewood Arsenal by way of Mr. Larry Sturdivan. As he indicated, these films are in the archives at the arsenal, and these experiments are no longer being conducted by the Department of the Army or the Department of Defense.

[The goat shooting film is marked as JFK exhibit F-309 for identification.]

Chairman STOKES. And do I also understand that the House Select Committee on Assassinations has not caused any experiments of this nature or any similar nature to be conducted?

Mr. MATHEWS. That is correct, Mr. Chairman.

Chairman STOKES. Thank you. I yield back to the gentleman of the District of Columbia.

Mr. FAUNTROY. Thank you, Mr. Chairman. I was just consulting with some of my colleagues here to see if any of them had ever shot a jackrabbit, in which case I would depend upon their judgment as to whether one hit in the head will raise it straight up in the air. I have been advised by the counsel that I might ask a member of the staff who had done the same.

Mr. FITHIAN. If the gentleman would yield, I have many years ago hunted these animals and what Mr. Sturdivan has testified to is not at all unusual.

Mr. FAUNTROY. Thank you.

Mr. Sturdivan, we are ready to see what happens to muscles.

Mr. STURDIVAN. Let me stop the film here and explain what is going to happen.

This goat is standing with his horns taped to a bar, only to preserve the aiming point of the bullet, which will come in from the right this time, not from the left, from the right, will strike the goat between the eyes. The black tape is there only to show the relative motion which we were presuming was going to be small. I should say they were presuming, since this film was taken back around 1948, I believe.

The first sequence will be a normal 24-frame-per-second view of this. This is a real time. First, we will observe the neuromuscular reaction, the goat will collapse then, and by the wiggling of his tail and the tenseness of the muscles we will see what I think has sometimes been called the decerebrate rigidity, and that takes place about a second after the shot and then slowly dissipates and you will see the goat slump, obviously dead.

The decerebrate reaction and terminus of the decerebrate reaction.

Now, this sequence will show the same goat, exactly the same shot, but in this case the movies are taken at 2,400 frames per second. I forgot to mention that the bullet is a .30-caliber military bullet. If I can stop this at an appropriate point.

Now, if you will look up at the forehead of the goat you may see a very small white spot, which was not visible on the last frame. If you can't, don't worry about it. What it is is the bullet entering the head of the goat. And if I can make sure that I have it going forward now. Four one-hundredths of a second after that impact then the neuromuscular reaction that I described begins to happen; the back legs go out, under the influence of the powerful muscles of the back legs, the front legs go upward and outward, that back arches, as the powerful back muscles overcome those of the abdomen. That was it.

Now, we will show a sequence here which I think will prove my assertion. This goat was shot under identical circumstances as the last one was except he is dead before the shot. The straps that you see are suspending him but he is free to swing. If you pushed on his head he would swing gently back and forth in this rack.

The bullet will come in from the right, again moving toward the left. In this case, the bullet is deflected as it goes out of the skull, and impacts on the goat near the spine, and then as you may have been able to see very dimly right behind the goat the bullet emerges from the back. It has deposited another few pound-feet per second of momentum in this goat. And then let me run it on through at real speed so you can see how much displacement that goat is given by the momentum that is deposited by the bullet.

If we can bring the house lights up, it will run for another 5 minutes without showing any movement in the goat.

Mr. MATHEWS. Lights, please. That's fine, please resume your seat.

Mr. FAUNTROY. Thank you.

What you have said to us, therefore, is that in the first instance the bullet in the first hypothetical, moving at the speed that you have suggested, would have come through the President's neck without much loss in velocity?

Mr. STURDIVAN. Right.

Mr. FAUNTROY. It would have had some, I would say, wobble, you would say yaw?

Mr. STURDIVAN. Yes.

Mr. FAUNTROY. Coming out because of what it hit? That it could possibly then go into the body of Governor Connally, in front of him, with a slight yaw, or at approximately the same speed, because it encountered no substantive resistance? Is that your testimony?

Mr. STURDIVAN. Roughly the same speed, not much loss in velocity?

Mr. FAUNTROY. And that it, your expert judgment, is logical that it could exit in Governor Connally's body do the damage that it did to the wrist and still lodge in the left thigh?

Mr. STURDIVAN. Yes, sir.

Mr. FAUNTROY. On the question of the apparent rearward motion of the President, you attributed that to nerve reactions to the massive activity in the brain?

Mr. STURDIVAN. Yes, sir; the neuromuscular response to the trauma in the brain.

Mr. FAUNTROY. And that the trauma there was caused by radial forces after the bullet had exited?

Mr. STURDIVAN. Yes, sir. During and after the——

Mr. FAUNTROY. During and after?

Mr. STURDIVAN. The passage of the bullet; yes. In other words, the radial velocity if imparted as the bullet goes through and continues after the bullet is long gone.

Mr. FAUNTROY. That explains the explosion?

Mr. STURDIVAN. Yes, sir, the explosion effect and the subsequent neuromuscular reaction that occurs roughly four one-hundredths of a second later.

Mr. FAUNTROY. Thank you, Mr. Chairman, I have no further questions, perhaps members of the committee may wish——

Chairman STOKES. The time of the gentleman has expired.

The Chair recognizes the gentleman from Connecticut, Mr. Dodd.

Mr. DODD. Thank you very much, Mr. Chairman.

Thank you, Mr. Sturdivan, for your time. I just have a couple of questions I would like to ask.

Yesterday, we had differing testimony. Maybe I should preface my remarks by asking you this: Do you have any specific background in anatomy. I noticed looking at your résumé your physics and statistics. Are you qualified to talk about anatomical responses and so forth, and, if so, what is your background in that area?

Mr. STURDIVAN. Yes, sir, I did take a considerable amount of biology in high school and college. I took some graduate courses in physiology, and then, of course, I continued that biological training on the job, because it is necessary part of wound ballistics.

Mr. DODD. You have had experiences in that during the duration of your professional experience?

Mr. STURDIVAN. Yes, sir, and before and during the duration.

Mr. DODD. Yesterday, Dr. Wecht and Dr. Baden, as far as I was concerned, anyway, disagreed on the response of human tissue, dead human tissue and living human tissue. Could you comment at all on that? Is there a significant difference or a substantial difference in testing projectiles, bullets, and so forth, through a cadaver as opposed to a living tissue?

Mr. STURDIVAN. Well, if you are looking for the effects on the tissue, the film was a dramatic example of how different it can be, in one case the neuromuscular action is there in live tissue and is obviously impossible in the dead tissue. If you are looking for the effects on the bullet, it would be very difficult to distinguish between the live and dead tissue.

In fact, there is enough biological variances so that I would presume that one group of living tissue would differ significantly from another group of living tissue. You can tell this by the next steak you bite on. Sometimes you get a tender steak, sometimes you get a tough one. There is a tremendous biological variance which probably masks out the difference.

Mr. DODD. As far as any dramatic effect on a bullet, the difference between living tissue and dead tissue would be minimal, is that right?

Mr. STURDIVAN. It would not be dramatic, I wouldn't expect it to be any different.

Mr. DODD. You showed us a film here of a living goat and what happened when that animal was struck in the skull, and then you showed us a film of a goat that was already dead. What would happen or could we predict anything dramatic occurring if you had a wounded animal and its anatomical response?

According to the films we see, the Zapruder film, it would appear that President Kennedy was first shot through the back, through the neck, then the skull shot. Would that shot, assuming, one, that it had not touched his spinal cord, have caused him to react the way he did at the time of the skull shot; and two, assume that it did touch the spinal cord, would there be dramatic differences in response, or is the time lapse too long to make any difference?

Mr. STURDIVAN. Well, of course it could not have struck his spinal cord directly because it would have had to penetrate through the body of the vertebrae to do so. But it would certainly—you see, a while ago I may have misled a little bit, I said there was no shock wave associated with a bullet passage. There is no shock wave in the tissue because the bullet is moving subsonically. There is a small shock wave caused by the impact.

In other words, the smacking force of the bullet impacting on the surface sends off a small shock wave. It is a matter of conjecture as to whether that shock wave would be strong enough to cause a mechanical stimulation of the cord, or whether if it did nick the small projection out from the side of the vertebrae, if the bullet passed near enough to that to fragment it, that the act of fragmenting that piece of bone might have been enough to cause a mechanical stimulation of a cord or a part of the cord or the radical velocity of the tissues.

As it moves out from the cavity it might well displace the cord through the holes that exist between the vertebrae where the nerves come out, and so forth. So, yes, a bullet passing that near the spine of the President could have caused a stimulus to his cord which would cause, or part of his cord, which might cause a visible reaction, but I can state with no certainty whether that would or would not have happened.

Mr. DODD. Are most of these tests that we saw conducted in 1964?

Mr. STURDIVAN. The Warren Commission tests were conducted in 1964. The goat films were conducted—they were taken in 1948, or thereabouts.

Mr. DODD. This is 1978. Would you do anything differently? Have we reached a state-of-the-art that we can be more specific and more scientific in terms of tests such as this, in order to reach conclusions. Thirty years ago, I presume that we have advanced scientifically in this area?

Mr. STURDIVAN. Well, yes. Humans have not changed significantly in that time, I don't imagine. Certainly the advance of science has carried us to greater heights, if you wish.

Mr. DODD. What would you do differently? What sort of test would you perform today, obviously excluding the ghoulish ones. Are there things that could be done today differently in order to conduct better tests?

Mr. STURDIVAN. Well, if we had knowledge—it is not a change in capability so much as a change in information, I think. If we had known that the critics were going to talk about massive deformation of bullets on cadaver wrists, we might have shot some bones, not necessarily wrists, but bones of equal size, at lower velocity, showing that the bones can be deformed when the bullet is not. But of course, we could have done that in 1964.

Mr. DODD. Would you recommend that today? Would you recommend we try and do something like that today?

Mr. STURDIVAN. As a scientist, I am totally confident that there is some point at which the velocity of the bullet will fall below the point where the bullet will be deformed, and that that is significantly above the velocity at which bone will be deformed. We know the mechanical properties of the gilding metal jacket, mechanical properties of bone, and we know there is a gap between.

The bullet is stronger than the bone, so there is some velocity at which we will smash bones but not smash bullets. At some lower velocity it would break bones but not smash them, in terms of bending, leverage, and so forth, might fracture a bone, but it would not cause a comminuted fracture. As some other lower velocity, it would just bounce off.

Mr. DODD. My time is running short here but I would like you to answer my question. The critics have raised the question.

Mr. STURDIVAN. Right.

Mr. DODD. And as a scientist, with those questions raised, do you think it is worth our while to conduct that kind of a test?

Mr. STURDIVAN. Personally, I don't. I can't answer from a viewpoint of somebody who is trying to quiet the critics.

Mr. DODD. Thank you.

Thank you, Mr. Chairman, I appreciate you letting me raise my questions out of order.

Chairman STOKES. The time of the gentleman has expired.

The gentleman from Ohio, Mr. Devine.

Mr. DEVINE. Mr. Chairman, could I request that exhibit No. 399 be handed to the witness. I would ask you, Mr. Sturdivan—is that correct?

Mr. STURDIVAN. Yes, sir, it is.

Mr. DEVINE. Did you have an opportunity at any time to examine the bullet that was found on the stretcher at the Parkland Hospital?

Mr. STURDIVAN. No, not this closely, sir.

Mr. DEVINE. Not on any previous occasion?

Mr. STURDIVAN. No, I never looked at it.

Mr. DEVINE. I would ask you to look at that particular exhibit that is in your hand at the moment and look at the configuration, any deformities that may appear thereon.

Mr. Sturdivan, we had before this committee a number of experts in many fields. We had one photographic analyst. We have had forensic pathologists. We had experts in many fields and we asked their opinion about a number of things and you obviously are an expert in the field of ballistics.

Based on what you know about the assassination of President Kennedy, the fact that a bullet entered the back of President Kennedy and emerged and conceivably then entered the body of Governor Connally and emerged and lodged itself some place going through the wrist, and perhaps the thigh, and perhaps that being the bullet that ended up on the stretcher in Parkland, in your opinion, as an expert, could the bullet that you hold in your hand now have passed through two bodies and touched some bone tissue and still emerged in that condition that some described as nearly pristine?

Mr. STURDIVAN. Yes, sir, it could have. The amount of soft tissue that it went through before it struck bone, the amount of bone that it struck, which wasn't extensive, at least before the wrist, the small amount of deformation indicating that it did not go through a great deal of bone at high velocity, which would have deformed it, caused it to have high drag, and so forth.

This bullet is quite capable of having gone through that much tissue; yes. It is slightly deformed which, through my calculations, indicate it must have been deformed on bone since it could not have deformed in soft tissue.

Mr. DEVINE. That is your best judgment as an expert in the field of ballistics; is that correct?

Mr. STURDIVAN. Yes, sir, it could have inflicted that damage.

Mr. DEVINE. Mr. Chairman, I have only one other question of Mr. Sturdivan. Again, as an expert in the field of ballistics, you are not troubled having seen the Zapruder pictures that the head moved in an anterior direction or posterior direction, I guess, the same direction from which the bullet was allegedly fired, that does not trouble you as an expert in the field having conducted tests in ballistics?

Mr. STURDIVAN. No, sir, the momentum of the bullet could not have thrown him in any direction violently. The neuromuscular reaction in which the heavy back muscles predominate over the lighter abdominal muscles would have thrown him backward no matter where the bullet came from, whether it entered the front, the side or the back of the head.

Mr. DEVINE. Then, to put it another way, it is entirely consistent that if the bullet came from the back, that the head may have also gone in a rearward position.

Mr. STURDIVAN. Yes, sir.

Mr. DEVINE. Thank you, Mr. Chairman.

Chairman STOKES. Mr. Sturdivan, do I understand that prior to Mr. Devine showing you this exhibit and asking you about it, that you had not previously been presented with this particular exhibit by anyone?

Mr. STURDIVAN. No, I had never held it in my hand before.

Chairman STOKES. The gentleman from Tennessee, Mr. Ford.

Mr. FORD. Thank you, Mr. Chairman.

I want to explore the damage caused to the skull due to what you call drag force and the different types of bullets.

I am not quite clear on drag force or the type of bullet, whether it is soft or hard bullet. Could you explain that?

Mr. STURDIVAN. Yes, sir, if I could recall that exhibit——

Mr. FORD. I don't have the exhibit number. Maybe Mr. Mathews, the counsel, could give us the number.

Mr. STURDIVAN. Mr. Mathews, do you remember the exhibit which has the drag force equation on it?

Mr. MATHEWS. That is F-115.

Mr. STURDIVAN. Congressman, as I pointed out before, the drag force is usually presented as an equation with the drag force on one side and everything else, including the "A" [mean presented area], on the other side. With the "A" on the other side, meaning that it would be multiplied by all of those other terms, this equation expresses the force that is exerted on the bullet.

Simultaneously, the bullet, of course, exerts the same force on the tissue. As that "A" increases dramatically, as the bullet goes from its normally oriented position to a 90-degree position, the area that you see increases dramatically and, therefore, the force increases dramatically.

As a bullet deforms, it also increases its presented area and, therefore, a deformed bullet will have a much higher drag than a nondeformed bullet.

The greater the deformation, the greater the velocity, the greater the force, the more dramatic that explosive effect is.

Mr. FORD. How long from the time that the bullet entered President Kennedy's head did the skull explode into fragments?

Mr. STURDIVAN. If you recall in the movies of the skull, the skull began to fragment while the bullet was still in passage and so, therefore, you might say that the skull began to come apart almost immediately, within microseconds of the impact continuing to fracture and move outward.

Mr. FORD. I am still concerned about the question I think my colleagues, Mr. Fauntroy, along with Mr. Devine, mentioned earlier about the direction of the bullet and the movement of President Kennedy's head and the time from the bullet entering the back of his head and the skull exploding? Why did the muscles in the neck and the back react to move the head backward rather than in the direction the bullet was traveling, which would have been forward?

Mr. STURDIVAN. The direction that was imparted by the bullet going forward would have been overcome by the neuromuscular reaction in about four one-hundredths of a second, if we can believe what happened to the animal would be the same in the human being.

Four one-hundredths of a second, I think, is well between frames on the Zapruder film. So, we wouldn't expect to see any forward motion of the head before we saw the violent backward movement caused by the neuromuscular reaction. In other words, there was very little time for him to move forward before he began to go backward.

Mr. FORD. Mr. Chairman, I don't have any further questions.

Chairman STOKES. The time of the gentleman has expired.

The gentleman from Indiana, Mr. Fithian.

Mr. FITHIAN. Thank you, Mr. Chairman. Mr. Sturdivan, have you or haven't you viewed the pathological data pertaining to the entrance wound in Governor Connally's back?

Mr. STURDIVAN. Yes, I did review the——

Mr. FITHIAN. I wanted to clarify something here. Perhaps I misheard. I thought in the exchange with Congressman Fauntroy, it was said that the hole was a round, penetrating hole, and I thought that the information we had before the panel yesterday was that it was sort of horizontal, as though the bullet struck somewhat perpindicular to the back.

Mr. STURDIVAN. As I recall from reviewing the same material that the forensic pathologists reviewed, the entry hole had been excised and destroyed by the surgeons at Parkland Memorial, but that a subsequent description of that hole was given which, as I recall, was elliptical, and in attempting to make a drawing of the shape of that hole, the surgeon drew an ellipse on a piece of paper.

The ellipse that was drawn measured 8 millimeters by 15 millimeters. However, I am not sure that indicated the size of the hole so much as the elliptical shape.

Mr. FITHIAN. So, is it your judgment, then, that the bullet had to have struck something else and was tumbling when it hit Governor Connally?

Mr. STURDIVAN. If it indeed had the shape that was described, then it would have to have been yawed and having been yawed, it would require that it struck something else before it struck the Governor.

Mr. FITHIAN. Thank you. In your experience with gelatin and other tissues, if the block is horizontal and the bullet is fired exactly in the horizontal plane, it seemed to me that in several experiments that you showed us that the bullet, as it went into the gelatin, had an upward bend to it; is that correct? Is that usual?

Mr. STURDIVAN. Yes, that happens universally. When the bullet begins to yaw, it develops a lift, like an aerodynamic lift on an airplane wing.

Mr. FITHIAN. And it doesn't make any difference which way it is yawing?

Mr. STURDIVAN. It will move in the direction it is yawing. If it yaws upwards, then it will tend to move upward. If it yaws down, then it would tend to move down.

Mr. FITHIAN. So, then, it is pretty specifically related to the angle at which it entered the tissue?

Mr. STURDIVAN. Exactly so. Unfortunately, the entrance yaw is unpredictable as to direction, so you really can't predict whether it is going to go upward, downward or to the right or left.

Mr. FITHIAN. I have one other question I would like to raise, Mr. Sturdivan. When the—I think you used the term radial velocity—builds up as it did inside President Kennedy's skull, you described very vividly that it was that force that caused the skull to blow away. If that were the element in determining the motion of the head, in what direction would the head have moved?

Mr. STURDIVAN. From looking at the exhibit, I think it is Zapruder frame 313, it looks to me that the material from the President's head is moving upward and toward the observer which would have been out to the right side of his skull.

Having relieved the pressure on that side and not having relieved the pressure on the other side would have pushed the President's head toward his left.

Mr. FITHIAN. Insofar as most of the missing skull fragments are forward in the forward half of the skull, would that have tended to contribute at all to the backward motion of the head?

Mr. STURDIVAN. It is possible that there would have been enough momentum lost in a forward direction that the skull might have moved backward or at least not move forward as rapidly as it would have otherwise.

However, if you recall, in the skull films, most of the momentum was to the side causing the skull to have a reaction in the opposite direction. But each of the skulls did move forward in the direction that the bullet took.

Mr. FITHIAN. But in those, the entry was considerably lower than in the actual case; isn't this correct?

Mr. STURDIVAN. Yes, but the exit, which is more important here, was approximately in the right place. That is, the fragments of the skull were moving out from essentially the same place. Where you are getting at is; no, I cannot exclude the fact the loss of momentum from the skull fragments leaving could have imparted a slight rearward motion, but that motion would not have been as dramatic as we saw.

Chairman STOKES. The time of the gentleman——

Mr. FITHIAN. I have one more question, Mr. Chairman. Thank you. Isn't a dry skull harder than a living one?

Mr. STURDIVAN. On the contrary, it is not quite as hard.

Chairman STOKES. The gentleman from Michigan, Mr. Sawyer.

Mr. SAWYER. I mainly want to see if I have gotten the import of what I consider to be the main thrust of your testimony. Do I understand correctly that the bullet striking the President's head would not have imparted any really perceptible motion in one direction or the other as far as the Zapruder film was concerned?

Mr. STURDIVAN. That is true, sir.

Mr. SAWYER. And that I presume, is what was illustrated on the striking of the dead goat that was hanging in suspension even though it went through the skull and lodged or hit the spine, that it didn't, at least I didn't perceive it moving, was that the objective of that test?

Mr. STURDIVAN. Yes, it was, sir. In fact, there was motion there but it was so slow that it was not perceptible on the film.

Mr. SAWYER. That was at a very high speed film, too, I assume.

Mr. STURDIVAN. It was 2,400 frames per second. Approximately 100 times the normal framing rate for a camera.

Mr. SAWYER. And the backward or stiffening back, and so forth, of the live goat, or the goat that was being killed by being shot in the head while it was alive, was due to that same muscular reaction of the back muscles you talked about as opposed to any force of the bullet?

Mr. STURDIVAN. Oh, yes, definitely, sir.

Mr. SAWYER. One other point that I would like to be sure that I have, too, and that is that if we assume that the deforming or destruction or damaging speed of a bullet is, let's say, 1,100 feet per second or lower or higher, and a bullet strikes an object that deforms or destructs, let's say, at a speed or an impact speed of 300 feet per second, that the bullet, as long as it is below its impact, its damage speed, can destroy or shatter the object with the lower damage threshold and itself not sustain any measurable damage because it is below its destruct or damage point: do I understand that correctly?

Mr. STURDIVAN. That is exactly true, sir. That, I think, may explain the statement of Dr. Baden when he said he observed a great number of handgun bullets which had smashed bones and not been severely deformed themselves because handgun bullets do typically strike around 1,000 feet per second, or less, which, according to my crude calculations, is below the deformation point of a bullet and certainly above the deformation point, the smashing point of a bone. So, I think that is dramatic evidence that it is true, there is that effect.

Mr. SAWYER. And in watching the Zapruder film where the President was struck in the back and through the throat as opposed to the second shot, you observed, I am sure, that the President raised his hands to his throat at that point, which, I presume, would indicate that the spinal cord was clearly not severed or he would not have been able to do that.

Mr. STURDIVAN. Right. If the spinal cord had been severed then he might not even have exhibited the neuromuscular reaction that I explained before.

Mr. SAWYER. But certainly, if it was severed that high, he would not have been able to raise his arms to the point of the wound.

Mr. STURDIVAN. No, sir.

Mr. SAWYER. Thank you. That is all I have, Mr. Chairman.

Chairman STOKES. The time of the gentleman has expired. The gentleman from Pennsylvania, Mr. Edgar.

Mr. EDGAR. Thank you, Mr. Chairman. I just have one question and then a comment which I would like to make.

Let's speculate for a moment that the three shots that left the right rear some place traveling in the direction of the car, that the first shot struck President Kennedy, causing him to clutch his throat, enter his back and come out his throat and that the second bullet struck Mr. Connally directly, going through his chest cavity, striking his rib, hitting his wrist, lodging in his thigh and that the third shot struck the President in the head causing the massive wounds that have been described over the last couple of days.

It's a different speculation than the one-bullet theory. What, in your area of expertise, leads you to believe that that speculation could not be true?

Mr. STURDIVAN. Well, in fact, nothing within my area of expertise leads me to believe that that could not be true.

Mr. EDGAR. So, it is possible that the second shot that I am speculating could have entered Governor Connally without passing through another person?

Mr. STURDIVAN. The only evidence that we have is the description of the entry wound on Governor Connally as being elliptical, which indicates that that bullet hit something before it hit Governor Connally.

Now, if it went if it went through 10,000 leaves or a few small twigs, it would be below the point where it would deform the bullet or deflect it to any considerable extent. It could have been yawed. So, as far as I am concerned, as an expert, I can only state that that bullet had been yawed before it hit Governor Connally, if it caused an elliptical wound in his back, which has been described.

Mr. EDGAR. Would it not be elliptical if it entered at an angle?

Mr. STURDIVAN. Yes, but if you make some geometrical drawings, you will find that in order for the ellipse to be roughly twice the diameter in one direction that it is in the other, it would have had to have entered at an angle that was 60 degrees from the normal. In other words, if this is a normal entry wound, it would had to have been tilted 60 degrees from that or only 30 degrees parallel to the surface.

A bullet entering at that angle would had to have roughly turned a 60-degree angle upon entry in order to exit out the front of the Governor and bullets just don't make abrupt 60-degree angle turns. Consequently, I can conclude from that, since the path was predominantly forward, that it was not an acute angle but a yawed bullet that entered him.

Mr. EDGAR. Thank you.

Just one final comment. I think it was unfortunate that you had not seen directly the physical evidence that we shared with you, the actual bullet that we have been discussing for most of the day. I do think, for the record, we should indicate that later today, we will have before us four members of a panel who will be able to talk in more detail about ballistics and deal with a number of other factors relating to the bullet itself, and they have had the opportunity to see that bullet as well as the guns that were used in this event.

Thank you, Mr. Chairman.

Mr. STURDIVAN. If I may. No, I had not held the bullet in my hand before, but I had studied, of course, the photographs and had access to the amount of deformation, and so forth, information on the amount of deformation.

Mr. EDGAR. Thank you.

Chairman STOKES. The gentleman from Michigan, Mr. Sawyer.

Mr. SAWYER. I just want to clarify something. I think you may have used an inadvertent word that I wanted to be sure was either corrected or confirmed. You said for the bullet to enter in an elliptical or create an elliptical entry wound into the back of Governor Connally, it would have had to have been deformed going through something before, whether it be the President's body or not. I don't know that you meant that.

From your earlier testimony, I thought you said it would not deform going through soft tissue, rather, would yaw as opposed to being deformed; am I correct on that?

Mr. STURDIVAN. I probably was speaking too fast. I intended to say that the bullet would have been undeformed, not deformed, but merely yawed by hitting something else.

Mr. SAWYER. Thank you.

Chairman STOKES. The time of the gentleman has expired.

Let me just ask one or two clarifying questions. You have just mentioned the fact you were shown photographs of exhibit CE 399; is that correct?

Mr. STURDIVAN. Yes, sir, I was.

Chairman STOKES. And asked for your opinion based upon a photograph? Were you asked for an opinion based upon a photograph?

Mr. STURDIVAN. I was asked for an opinion with respect to the amount of deformation, and so forth, based on photographs.

Chairman STOKES. Right. So, what you are saying here today, you were consulted with reference to this particular missile?

Mr. STURDIVAN. In interviewing by the staff, we did cover that point several times, yes, sir.

Chairman STOKES. That was our staff you have reference to, the House Select Committee staff?

Mr. STURDIVAN. Yes, your staff, the staff of your committee.

Chairman STOKES. Thank you. Counsel for the committee, Mr. Mathews.

Mr. MATHEWS. Mr. Chairman, could we put into the record JFK exhibit F-117, which is the gelatin shot film; JFK F-304, which is the tomato shot film; JFK F-305, which is the skeleton experiments; and JFK F-309, which is the goat shooting film. If I may have that made part of the record, Mr. Chairman.

Chairman STOKES. Without objection, they may be entered into the record at this point.

[JFK exhibits, F-117, F-304, F-305, and F-309, are retained in committee files.]

Chairman STOKES. Mr. Sturdivan, as a witness before our committee, under our rules, you are entitled to 5 minutes at the conclusion of your testimony for the purpose of explaining or amplifying, or in any way expanding upon the testimony you have given this committee.

On behalf of the committee, I, at this time, extend to you 5 minutes for that purpose.

Mr. STURDIVAN. Thank you, sir. I don't think that I have anything really to add to the testimony, to amplify, or so forth.

I should, however, mention the fact that I am not here as a representative of the U.S. Army, that the opinions that I represent here are my own.

Although the Army has very graciously allowed me administrative leave to appear as an expert witness, I am not a representative of the Army, and I do wish to thank the members of the committee and the members of the staff, especially Mr. Mathews, for the help that they have given me and the support, particularly when the microphone failed, and for dragging me through relatively unscathed.

Thank you very much.

Chairman STOKES. Thank you, you have been very helpful to the committee. We appreciate the cooperation you have given the committee and the staff. We appreciate having had your testimony here today. Thank you very much.

The Chair will recess the hearings until 1:30 this afternoon. We will reconvene at 1:30.

[Whereupon, at 12:25 p.m., the hearing recessed, to reconvene at 1:30 p.m.]

[Additional material included at the request of Congressman Timothy Wirth.]