UNITED STATES DISTRICT COURT

FOR THE

DISTRICT OF COLUMBIA

STENOGRAPHIC TRANSCRIPT

FRIENDS FOR ALL CHILDREN, INC., et al, Plaintiffs, -vs- LOCKHEED AIRCRAFT CORPORATION, Defendant and Third-Party Plaintiff, -vs- THE UNITED STATES OF AMERICA, Third-Party Defendant,	CIVIL ACTION NO. 76-0544

Arlington, Virginia

Tuesday, October 6, 1981

DEPOSITION OF: DR. ROBERT R. McMEEKIN

Mattingly Reporting, Inc.
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Fairfax, Va. 22032

CMH/er

UNITED STATES DISTRICT COURT

FOR THE

DISTRICT OF COLUMBIA

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FRIENDS FOR ALL CHILDREN, INC., et al, :

Plaintiffs, :

-vs- :

LOCKHEED AIRCRAFT CORPORATION, : CIVIL ACTION NO. 76-0544

Defendant and Third-Party Plaintiff, :

-vs- :

THE UNITED STATES OF AMERICA, :

Third-Party Defendant, :

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Arlington, Virginia

Tuesday, October 6, 1981

Deposition of Dr. Robert R. McMeekin, a witness for the Defendant and Third-Party Plaintiff, called for examination by counsel for the Plaintiffs in the above-entitled action, pursuant to notice the witness being duly sworn by CLAIREEN M. HOLMES, a Notary PUblic in and for the Commonwealth of Virginia at Large, at the offices of Lewis, Wilson, Lewis and Jones, LTD, 2054 North Fourteenth Street, Arlington, Virginia, commencing at 1:50 o'clock p.m., the proceedings being taken down by stenotype by CLAIREEN M. HOLMES and transcribed under her direction.

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APPEARANCES:

On behalf of the Plaintiffs:

OREN R. LEWIS, JR., ESQUIRE
Lewis, Wilson, Lewis & Jones, LTD.
2054 North Fourteenth Street
Arlington, Virginia 22216

On behalf of the Defendant and Third-Party Plaintiff

CARROLL E. DUBUC, ESQUIRE
Haight, Gardner, Poor and Havens
Federal Bar Building, Tenth Floor
1819 H Street, N.W.
Washington, D.C. 20006

Also Present:

Robert W. Lewis

C O N T E N T S

E X H I B I T S

Whereupon,

DR. ROBERT R. McMEEKIN,

a witness for the Defendant and Third-Party Plaintiff, called for examination by counsel for the Plaintiffs, having been first duly sworn by the Notary Public, was examined and testified as follows:

MR. DUBUC: I would like to state on the record that Dr. McMeekin, who is described in the pretrial brief as testifying to various things, will not be offered as was Dr. Horne not offered; the probable absence of any impact or deacceleration trauma in connection with the emergency landing causing any injury to the Plaintiff. Deacceleration trauma, G-Force areas are being covered by other witnesses, as you already know from depositions. He is not being offered on that subject. He is being offered on the other subject described in the pretrial brief. He will be offered at trial on those other subjects, but not on the G-Force.

MR. LEWIS: When did you eliminate that election?

MR. DUBUC: Oh, I don't know. Probably in the last week or two.

MR. LEWIS: I mean, that area is included in the description.

MR. DUBUC: Yes. Well, I am trying to save you some time. You have got other witnesses. Dr. Gaume, who has testified and Dr. Turnbow who will be here this week to testify. So, in the interest of speeding up the trial and limiting the testimony and all the rest of the stuff, we are only offering Dr. McMeekin on the areas that remain after the elimination of that one.

EXAMINATION BY COUNSEL FOR PLAINTIFFS:

BY MR. LEWIS:

Q Dr., would you state your full name, please sir?

A My name is Dr. Robert McMeekin.

Q And what is your address, please, sir?

A [redacted] Kensington, Maryland.

Q Now Doctor, when were you asked by the Lockheed Aircraft Corporation to consult for them?

MR. DUBUC: By Lockheed?

MR. LEWIS: Yes.

THE WITNESS: I was never contacted by Lockheed.

BY MR. LEWIS:

Q Well, you do understand that the gentleman that is here is an attorney for Lockheed?

A I do understand that.

Q Well, did you ever discuss the C5A crash or any aspect of it, sir, with any representative of the Lockheed

Aircraft Corporation?

A I discussed it with him, yes.

Q You are speaking of Mr. Dubuc?

A Right.

Q When was that, sir?

A I think the first time was in mid July.

Q Okay. Now Doctor, I am not, you know, I'm not making a distinction between Lockheed and their legal representative and you may think that I am. I just want to make sure that I am not being unfair in my question to you. When I say consulted by Lockheed, I mean Lockheed or its attorneys or anybody else speaking for --

MR. DUBUC: You realize, for the record, that Mr. Piper is not here. He suggested that we go ahead with the deposition anyway. So, he has asked me to make whatever objections Mr. Piper would make and I will make those, if that is what you're getting at.

MR. LEWIS: No. No. No. I just want to understand. So then you are not -- you have never been asked by Lockheed or any of its representatives, is that your understanding, Doctor?

THE WITNESS: I suppose I could elaborate.

BY MR. LEWIS:

Q Please.

A I was -- first spoke to people from the Justice Department who asked me if I were aware of this case, if I had worked on the case and I told them that I had not and they asked me if, from that standpoint, I would look at it and they introduced me to Mr. Dubuc and that is the way I became involved.

Q I understand, sir. And did they ask you to cooperate with Mr. Dubuc, to assist him? I am not suggesting anything improper by that.

A Yes. That is correct.

Q Because you see, I have a statement which was in the Lockheed pretrial or trial brief in which they suggested that you would be called as a witness for the Lockheed Aircraft Corporation, which is how I came to the conclusion --

A Right. Yes.

Q -- that I have.

What documents have you had an opportunity to review, Doctor?

A I reviewed a great deal of material that the firm provided me.

Q When you say the firm -- excuse me. I don't mean to interrupt you, forgive me, but do you mean --

A Haight, Gardner.

Q Haight, Gardner. All right.

A I did not have to rely on that -- on very much of that in order to come to the opinion on the area in which I was asked to look.

Q Well, in the submission of the Lockheed Aircraft Corporation, they suggest that you are going to testify on the descent profile of this accident, you're going to discuss rapid decompression -- I am paraphrasing, just so you understand that. The question of hypoxia and the probable absence of any impact or deacceleration trauma.

MR. DUBUC: I just took that out.

MR. LEWIS: I know. I am just telling the doctor what you filed, Mr. Dubuc. I'd be glad to show you, Doctor, if there is any question, Mr. Dubuc, about it.

MR. DUBUC: All right. With that qualification, go ahead.

BY MR. LEWIS:

Q And I just wondered if you understood that they had originally asked you to do all these things.

A I certainly haven't had any time to go over all that material in detail and I do not anticipate that I would in the future.

Q Can you tell me what material you did review carefully?

A I guess the material I went over carefully were the descent profile --

Q Okay.

A -- and I read several reports from a number of the other witnesses regarding hypoxia. I believe those were Dr. Gaume, Dr. Davis. That is all that comes to mind.

Q All right, sir. Anything else?

A No. As I said, I read a great deal of other material, but I was hardly just skimming. In fact, I went through, I suppose, 20 pounds of material in an evening and as you can imagine --

Q Well, sir, I have been connected with this case for quite awhile and I am fully familiar with the fact that both in numbers of words and sheer weight it is a lot of stuff.

A I read some of the witness' statements, some of the testimony of some of the witnesses.

Q I would be interested in knowing which ones you read about and let me, so that it is not a mystery, sir, tell you why I want to know. The only way that I can tell whether or not Lockheed has given you all of the data that at least our people think is material to the questions, you know, is to find out what you got.

A Okay. I don't recall the specific materials. I do not have that list with me.

Q How long did you spend on the review of the materials? I will approach it that way.

A I would say three or four evenings -- three or four hours one evening.

Q So, including reviewing the things that you have described specifically, the reports of these two men and the descent profile, you spent three to four hours in one evening and that is the only --

A And I also attended a one-day session where a large number of the experts were together and --

Q All right.

A -- and we did some findings.

Q Was that on August the 15th of this year, sir?

A It was in August. I believe it may have been the 15th.

Q So you got whatever data that might have provided plus your review of three or four hours?

A That is correct.

Q And that is the total amount of study that you have been able to devote to that?

A That's correct.

Q Now, I have read the profile or whatever it is called of accident reconstruction some analysis of injuries, which you were one of the authors of, sir, and I don't know that I know where it was published, but I guess you are familiar with it. And you do remember that, sir?

A (Indicating in the affirmative.)

Q Where was that published, do you know?

A I believe that was from the University of Virginia press, was it not? A book entitled Aircraft Crash Worthiness.

Q Okay. Did you follow the procedures described in your article in your analysis of this crash, sir?

A I am not sure exactly what all we discussed in there. I certainly -- I did not go to the crash scene and that would be something, if I were undertaking a complete investigation of all aspects of it, quality aspects, I might have done.

Q Did you review the motion pictures of the crash scene, for example?

A I was not aware that there are motion pictures of the crash scene.

Q There are. Post-crash. There's also a motion picture in which a helicopter undertakes to follow the crash, the path, the flight path of the airplane as it hit the ground once and then went up in the air and then struck again and again and so forth, to fly over it and in the course photograph the scene. And you haven't seen that either?

A No, sir. I was not concerned with that portion of the accident.

Q I understand. And I am not, you know, making a bad judgment that you should or shouldn't, sir. I am just trying to identify what it is that you saw.

Did you have an opportunity to review any of the data involving the injuries to any of the persons in the troop compartment?

A Injuries to persons in the troop compartment.

Q Any medical records?

A I did not review medical records.

Q Or, I guess there are probably not autopsies, but I call them autopsies. In any event, the identification records that show what parts of the persons were damaged and in what ways?

A No.

Q Did you review those?

A I did not.

Q As I understand the thesis that you suggest in the article that I have mentioned, and I may misstate it and I want you to correct me if I do, Doctor, because it is your area and not mine, but as I understand it, one of the points that you made is that before you can understand clearly the forces and events that occurred in the crash, that you need first to get all the data including the injuries to the people, where they were located and then try to put that together with what is a hypothesis from the engineering people to see whether they make sense. I know that is probably crudely stated, but is that one of the points?

A If I were undertaking the investigation of the accident, that is correct.

Q You see, I am not just asking about you. I am talking about sort of us. In other words, the people that are really going into this thing in addition to yourself. The way that you found to be very satisfactory to understand what happened in the accident is to look at the injuries and work back from that?

A Oh, I think that all of the information that you can get is very helpful. You never know where you can find some helpful information.

Q And things like fractures, for example, can give you information about G-Forces, for example, or at least the type of force and the direction of force and the magnitude of force, isn't that right, sir?

A That's correct.

Q And so to really understand the engineering contentions or theories, you want to know about injuries, among other things?

A If I were getting involved in the engineering aspect, yes.

Q Now, you do do this from time to time, do you not, sir?

A I do.

Q It is my understanding that you are a pathologist, is that correct?

A That is correct.

Q And one of your areas of interest is the understanding of the engineering aspects of a crash?

A That's correct.

Q From among other things, the injuries or damage to the dead persons --

A That's correct.

Q -- is that correct?

A That's correct.

Q Now, I notice also in your article that you say, under your Conclusions and Recommendations, Section 2-F "be careful to recognize the "odd" injury, the case that stands out from the other." What does that mean, sir?

A I suppose, by example, if we were to examine all of the members of a -- all of the faded members, people aboard an aircraft and you found all of them had seatbelt injuries except for one, we would then go and try to figure out why that one person did not. Or, if one person was badly burned and others were not, we would want to know why, that type of thing.

Q Now, what witness' statements have you had an opportunity to review carefully?

A By name, I couldn't tell you by name.

Q Well, sir, in arriving at any of the conclusions that you have arrived at, can you tell me what witness information you considered? In other words, what premises or factual premises have you assumed?

A My understanding from the witness' statements was that the people upstairs in the troop compartment during the decompression, those children, there didn't seem to be any change in what the children were doing.

Q All right. Let me see if I understand it. The reports that you received were that both before -- that there was no difference in the behavior or appearance of the children from before to after the explosive decompression, is that what you're saying, sir?

A Right.

Q All right. Any other factual assumptions?

A I have no information that would indicate there has been any hypoxic damage to anyone as a result of decompression. There's crew members who were performing duties, continued to perform their duties.

Q Any others? Any other factual premises that you have?

A From the witness' statements?

Q Yes, sir.

A No, not that I recall.

Q Well, then these would be the only significant ones then?

A That is all that comes to mind. Yes, sir.

Q I am not -- what I'm trying to find, sir, is since this is your area and not mine and I have some knowledge of the facts, I am trying to find out what the assumptions from the facts that you were given that you have used as a predicate, if that is a fair way of putting it, or a basis for your conclusions, which I'm going to ask you now. And I am talking about from the witness' statements right now, sir. These are the primary ones?

A Right.

Q And there aren't any others that you can recall that are important?

A Well, as I say, I used the information regarding the descent profile.

Q I understand that.

A Right.

Q But I'm speaking of what the people that were on the airplane said in their testimony or witness' statements.

A Correct. Yes, sir.

Q You assumed that all other persons on the airplane, even those without oxygen, remained conscious at all times?

A As far as I know, yes, sir.

Q All right. And when you say there was no hypoxic damage to anyone, you assume that on the basis of medical examinations, there is no problems with the children, is that correct?

A From the information that I have obtained, yes.

Q All right. For example, if there was a very widespread -- do you know anything about whether or not there is substantial evidence of neurological problems with this group of children?

A I do not.

Q That would be something important to know, would it not?

A That would be something to factor in, yes.

Q And whether or not the persons without oxygen were able to remain conscious would be, again, something you would want to know?

A I would.

Q And whether or not the children, from observation, remained the same would also be important? In other words, from their appearance and their behavior, the way they acted would be quite important, wouldn't it?

A That will be something to factor out and I don't know necessarily if they changed what they were doing or --

Q Well, when I say changed, I mean if, for example, the children were conscious at one point and unconscious at another, that would be a change in their condition --

A Yes, sir.

Q -- that is the sort of thing that I am talking about.

A Yes, sir.

Q That would be important, wouldn't it?

A I would be interested to know that, yes.

Q Were you shown the testimony or any statements involving what happened to a child by the name of Ly DeBolt?

A Ly DeBolt?

Q Ly DeBolt.

A I don't remember any specific names of the children, but where was Ly DeBolt located?

Q She was in the troop compartment.

MR. DUBUC: No, sir, she was not.

BY MR. LEWIS:

Q Excuse me. She was in the cargo compartment.

A I saw no information about people in the cargo compartment.

Q Well, there wouldn't be any difference as far as -- would it make a difference if they were in the cargo compartment or the troop compartment as far as explosive decompression was concerned?

A The pressures would be the same.

Q I mean, if you would want to know if somebody became unconscious in the troop compartment or somebody became unconscious in the cargo compartment, you would want to know both of those facts, wouldn't you?

A (Indicating in the affirmative.)

Q Did anybody report to you or give you the opportunity to review the statement of Sgt. Wise who was in the cargo compartment?

A Was he a load master or --

Q I don't remember his position. He reported that he passed out from the lack of -- being unable to breathe, certainly under the explosive decompression.

A I believe I did hear about him.

Q When did you hear about that?

A I also heard that he had some rather severe injuries. I don't know the exact nature of them. That would influence the weightthat that would give to the story that he was inconscious.

Q Did you decide that he was not unconscious?

A I think that I would conclude that he was not, since I have no evidence that the people upstairs were unconscious and I have plenty of reasons to understand why, if you were severly injured. He may not in fact recollect.

Q And you read no witness' testimony or statements that gave any suggestion that the children might be unconscious?

A No.

Q All right. Now, in your article, Doctor, you stated, among other things, in Section 1, under the Conclusions, the aviation pathologist can play a role in aircraft-accident investigation that exceeded the activity previously pursued in determing cause of death and identification of the deceased. He may aid the technical personnel of aircraft-accident investigation board in determining the cause and manner of the accident.

Do you still agree with that?

A Well, you have got the advantage. You are --

Q I am not trying to be difficult, sir. I will be glad to share it with you, but if you will take my word for this --

A Well, it has been quite sometime. I forget how long ago this was that this was published.

Q I was just reading the first -- see where it says Conclusions and Recommendations, sir?

A Um-hum.

Q Do you see Item 1 there?

A Um-hum.

Q That is what I undertook to read and I think I read it accurately.

A Um-hum.

Q That is still a valid point, isn't it sir?

A That's correct.

Q I beg your pardon, sir?

A Yes.

Q Now, can you tell me, Doctor, is it a practice of the Air Force in accidents of this type to perform autopsies on the bodies of the deceased persons?

A The military services normally perform autopsies on the fatally injured crew members in noncombat accidents.

Q Which this would be.

A They would probably consider this to be a combat accident.

Q Why?

A Most of the accidents in Viet Nam at that time were considered to be combat related accidents.

Q Well, a combat accident is an accident in that the plane is disabled through combat, is that right?

A Well, you can do a lot of things with definitions, as you know. I don't know with certainty why they made the decision in which they did. I suppose that perhaps it might be that they didn't want their personnel going out in a combat area, working on accident investigations.

Q Well, do you know where the bodies were taken following this crash?

A I do not.

Q Do you know of a morturary in Thailand, sir?

A Thailand?

Q Yes, sir.

A I don't.

Q Well, if the bodies are recovered and are taken to a safe place --

A (Indicating in the affirmative.)

Q -- then it would be appropriate to do autopsies on the crew members that died, is that correct?

A On the crew members that died and the services would normally do that, yes.

Q And one of the reasons for doing that is to try to determine cause of death so that safety can be promoted, is that not true, sir?

A That is correct.

Q And if this crash was a crash in which the integrity of the weapon system was under investigation, it would be important to know whatever an autopsy would produce on that, would it not?

A I think that they make every effort where possible to perform an autopsy. There's a number of reasons why they would not in combat areas.

Q I understand that, but if they had the opportunity, under the standing procedures, they should have done autopsies, if they could do it safely and without doing it under combat conditions?

A I would think that they probably would, yes.

Q And that would be ordinary procedure, would it not?

A The ordinary procedure would be, if it were feasible, that they would try to do that.

Q That is all I am trying to find out, sir.

A Yes.

Q Do you know whether autopsies were performed in this case?

A I do not.

Q Now, under your Conclusions and Recommendations in the same article, sir, under Item 2-H, H as in Henry, it reads formulated preliminary, medically based hypothesis and find out whether it is congruent with any engineering hypothesis being formulated.

Is that a reasonable way to proceed in understanding what happened in the crash?

A That's right.

(Discussion off the record.)

MR. DUBUC: If we are going to be reading from this article, should we mark the article so we know --

MR. LEWIS: Yes, certainly. Well, I'll have to get another one. I have some notes on this.

MR. DUBUC: Well, can we get another one? It would speed things up. He's already asked to look at it once.

MR. LEWIS: I would do that except for the fact that I have got my own notes and markings on here, and I will try to get a copy, but since the article is published in the Public Domain, it is not any secret.

MR. DUBUC: No --

MR. LEWIS: I am reading from accident reconstruction from analysis of injuries by Joseph M. Ballo, B-a-l-l-o, Major, M.C., U.S.A., Division of Aerospace Pathology, Armed Forces Institute of Pathology, Washington, D.C.; and Robert M. -- correction, R. McMeekin, spelled M-c-M-e-e-k-i-n, McMeekin (forgive me, sir), L.T.C., M.C./F.S., U.S.A., Chief Division of Aerospace Pathology, Armed Forces Institute of Pathology, Washington, D.C. The first page appears to have a page number B14-1. This is a published article, is it not?

MR. DUBUC: My point is not the title of the article, but under our long existing practice of these depositions if you or if I asked somebody about an article, that it is usually one to mark and one made available so that the witness can see it.

MR. LEWIS: That is in Court, Mr. Dubuc.

MR. DUBUC: That has been in depositions, Mr. Lewis.

MR. LEWIS: I have no objection to showing the doctor this article at any time. If he will trust me that I am reading it accurately, if there is any reason to think that I am not, he won't insult me at all and I'll be glad to adjourne and let him read the whole thing. I am not trying to make it a mystery.

MR. DUBUC: Why don't we just adjourn and have a copy made. I'm sure you have an original in your office that has not been marked up.

MR. LEWIS: I may, but I don't know where it is right now. This is the only one that I have and I have it marked up.

MR. DUBUC: Well, can we agree that a copy will be marked?

MR. LEWIS: I will try to get a copy and we'll mark it and we will call it McMeekin Deposition Exhibit Number 1 for identification, which will be the Accident Reconstruction from Analysis of Injuries by Drs. Ballo and McMeekin.

MR. DUBUC: All right.

(The document referred to will be marked McMeekin Deposition Exhibit Number 1 for identification.)

BY MR. LEWIS:

Q Now, Item 3 in Page B14-9 reads each injury should be examined from the standpoint of, and then there are A, B, C, D, and E. And, A is the magnitude of the force required to produce it.

Does that sound familiar, sir?

A Yes.

Q And what does that mean, Doctor?

A If we were looking at -- if I were looking at physical injuries, I would try to determine how severe each injury was.

Q From the tissue damage, sir?

A (Indicating in the affirmative.)

Q Would the broken bones and whether there is tissue torn off or how it is located? In other words, the way the cadaver appears, is that it?

A That's correct.

Q If it is a cadaver or the injury to the living person?

A I don't often see living persons in my work.

Q I understand, but you may have an opportunity to see medical reports, is that correct, sir?

A Yes.

Q And if you were trying to understand from a pathological standpoint what forces were involved and what happened in the plane crash, you would want to know those things, wouldn't you?

A I would.

Q And if somebody else is doing the pathological examination, I don't mean as a pathologist, as a physician doing pathological work, they would presumably want to do the same thing, isn't that correct?

A Yes, sir.

Q That is the way it should be done in any event, isn't that correct?

A If the circumstances permit and --

Q If there is an opportunity to do it and --

MR. DUBUC: Would you let him finish his answer?

MR. LEWIS: I'm sorry. I didn't mean to interrupt.

(Discussion off the record.)

THE WITNESS: In a case such as this where you have a large number of fatalities, it is not always possible to do all of the things that one might otherwise do. Considering the condition of the bodies, you might do the things you felt most important first, which might preclude some of the other things.

BY MR. LEWIS:

Q Well, if the bodies were all taken to a safe place, for example, a morturary in Thailand which was not in a state of war, where they were all -- you know, in the United States Army or whatever, service morturary, where they have complete facilities to do autopsies and refrigerate bodies and that sort of thing, then one would want to do autopsies to try to understand and make reports of the type of injuries that each body sustained.

A Well, there are certain physical limits, too --

Q But you would want to do some anyway, wouldn't you?

MR. DUBUC: Let him finish his answer.

THE WITNESS: I don't know how many fatalities there were here, but I know how many autopsies I can do in in a laboratory and break it and make it a force.

Q Well, you do that, don't you?

A. I don't.

Q Or somebody did it?

A. You can do that, yes.

Q And so that among other things if you have a crash in which a long bone is broken under some circumstances, one might break it -- make a production from that particular fracture, isn't that so?

A. In some cases perhaps.

Q But you say in Item 4 threshold or injury production have been discussed for abdominal and thoraxic posterior, the spine, the extremities, the head and the thoraxic. And you do discuss that in your article, don't you?

A. I don't recall what all we discussed in the article.

Q Well, for example, on Page B14-7 under Extremities, it says impact studies have defined a tolerance level for the human femur. Now, it goes on and it discussed that. The femur is a long bone, isn't it?

A. That's correct.

Q In lay terms?

A. That's right.

a day and if I am really working hard and a pretty long day, I might do eight.

BY MR. LEWIS:

Q But you would want to do some in this situation, wouldn't you?

A I would do some examination and descriptions, yes, sir.

Q And particularly those people that died in the troop compartment would be important, wouldn't it, to understand what happened to these children, for example.

A Perhaps. You do the things that are necessary to answer the questions that you pose. The first job is going to be to pose the questions and sometimes they are posed for you.

Q All right. Now, the threshold for injury production is something that -- a fair amount of knowledge is available, is that not right?

A Not as much as we would like.

Q I understand. Well, there is information about what it takes to break a long bone under ordinary circumstances, isn't that right?

A There is information about breaking long bones. I am not sure about ordinary circumstances. We can put the bone

Q I understand that there are others. That is one of them, isn't that right, sir?

A That is correct.

Q And when you say tolerance level, what do you mean, Doctor?

MR. DUBUC: Do you mean in that article?

BY MR. LEWIS:

Q What does it mean in general terms?

A Depending on the context you are working in, it can either mean tolerance, survival versus nonsurvival. It could mean the difference between no injury or some injury.

Q Do you know Dr. Mason, an English man?

A Yes, I do.

Q Is he a pathologist like you?

A He is. Yes.

Q And is he --

A I don't know what you mean by like me?

Q Well, forgive me, sir.

A Also.

Q Also is probably a better way to put it, Doctor. He is noticeably older than you, sir. He is considered in the field of aircraft pathology a leading expert, is he not?

A He is certainly well known in the field. Yes.

Q And from your observation, a competent person?

A Yes, I would say so.

MR. LEWIS: Let's take a brief recess.

(A short recess was taken.)

BY MR. LEWIS: (Resuming)

Q Do you have any other information, sir, other than what you and I have talked about here this afternoon, on the factual basis now, on which you base your opinions with respect to hypoxia and decompression? You mentioned here that you read Dr. Gaume's report and Davis' report and you made these factual premises that we talked about in lieu of your being able to name the people whose depositions you read. You said that there were apparently no change in the appearance or condition of the children before and after the explosive decompression, that there was no evidence of any neurological injuries to the children and that apparently people without oxygen were able to perform fine.

A (Indicating in the affirmative.)

Q That is not necessarily the way you said it, but that is the way I heard it and is that basically --

A Yes. Through all the materials that I read I found nothing to suggest to me that hypoxia hindered anybody from performing their duties or produced any injuries in any of the people.

Q Do you know of any crew members that worked without oxygen?

A For a portion of the time, yes.

Q But do you know anybody that was without oxygen for the whole time?

A I don't recall specifically.

Q And you have never seen any reports involving the condition of anybody that either died or was injured or had any kind of condition reported that was in the troop compartment?

A Injuries in the troop compartment you said?

Q Yes, sir.

A No, I did understand that there was injuries.

Q But you haven't seen the data on them, is my question.

A I have not seen autopsies or medical reports, no.

Q So you don't have any accurate -- I mean, if you do, I want to ask you about it. Do you have reports on what happened to various people in the troop compartment?

A From the information that I read, I heard that the people that were injured, the adults who were injured, were not strapped in seats.

Q But you don't know what bones were broken and where they were precisely located and all of this sort of thing that you would do if you were doing a review?

A. No, I don't.

MR. LEWIS: All right. It is my understanding, Mr. Dubuc, that he is not going to talk about any aspects of the deacceleration part of the case, is that correct?

MR. DUBUC: That is right.

THE WITNESS: Correct.

BY MR. LEWIS:

Q Do you know how many people died in the troop compartment?

A. I understand that there were three people who died in the troop compartment.

Q And you haven't seen any reports on them as to what part of their bodies were injured or damaged?

A. Only what was in the depositions and the -- the witness' statements and the depositions.

Q You have me there, Doctor, because I don't know which depositions you read. Can you tell me what --

A. A witnesses. Witnesses.

Q Okay.

A. People who were on board.

Q Well, were there any civilian women killed on the trip?

A I don't remember which two. I understand that there were two adults in the troop compartment that were killed.

Q Do you know whether they were men or women?

A I would be guessing, so I don't want to do that.

Q Well, I am interested in precision, to the extent that you can give it to me.

A All right.

Q Do you know when they died? From a time standpoint, sir?

A I think I am sure, but again, I would be guessing, so I would not.

Q Then you don't know what parts of their bodies were damaged, from a technical precision standpoint as you would do it if you were studying it from a pathological standpoint, do you?

A That's correct.

Q How many babies died in the troop compartment?

A I understand that one baby died in the troop compartment.

Q Do you know whether there was an autopsy done of that child?

A. I do not.

Q. Can you tell me what your opinion is with respect to explosive decompression?

A. My opinion regarding the explosive decompression would be that there were no incapacitating or long term effects of the decompression.

Q. Sir --

A. You didn't phrase it to hypoxia.

Q. And you base that on the data, the factual assumptions that you have given me plus the reports of Dr. Davis and Gaume, is that correct?

A. Plus my own experience and in addition we ran a study in our own laboratory.

Q. Which study did you run in your laboratory?

A. I had my staff run a similar descent profile in the altitude chamber, having a subject connected to a device to determine how well he was being supplied with oxygen.

Q. Which one of these reports is that, Doctor? Which list, so that I can identify that.

MR. DUBUC: It is Exhibit D1222.

MR. LEWIS: May I see the original?

MR. DUBUC: You have got a copy.

MR. LEWIS: I know I do. Do you want to wait or do you want to indulge and let me see yours?

MR. DUBUC: Well, I will wait to see if you can find it. I have got one only.

MR. LEWIS: What is the number?

MR. DUBUC: D1222.

BY MR. LEWIS:

Q And what is your opinion with respect to -- is this hypoxia and explosive decompression or just explosive decompression?

A They are both -- we ran two studies here. One two two is a series. Her I see one two two and -- one two two two and one two two three. I had not seen these marks.

Q May I see them? I have one two two two.

A Should I show him?

MR. DUBUC: Oh, one two two and one two three.

THE WITNESS: One two two two and one two two three.

BY MR. LEWIS:

Q What is one two two two?

A This is a situation simulating as best we could the decompression discent profile from the MADAR data.

Q All right. What does variable 1 mean?

A That is elapsed time.
Q And what are these stations, one through seventeen?
A That is observation data number.
Q I don't understand these. What is variable number 2?
A Variable number 2 is the pressure altitude in the altitude chamber.
Q And variable number 3?
A Is the percent saturation, oxygen saturation of the blood.
Q All right. Now, did you use -- what age babies did you use?
A This was an adult.
Q An adult. How old was the adult?
A I believe he was 32 years old.
Q Why didn't you use a child?
A We didn't have children available to us that could give us informed consent for a study.
Q Do you have any children, sir?
A I do.
Q You wouldn't consider doing this test on them, would you?
A I would be more than willing to have my children

do something like that.

Q Tell me what was the explosive decompression at the time.

A Approximately one to two tenths of a second.

Q Did the subject have altitude -- did it have any oxygen prior to the explosive decompression?

A They did not.

Q What is the name of the subject?

A The name of the subject?

Q Yes, sir.

A Capt. James Dixon I believe was the subject.

Q And he was the only one you used, right?

A Yes, sir.

Q And so what did you do?

A We took them to --

Q You say them -- I mean --

A All right. I don't recall. There may have been someone else physically in the chamber with him at the same time.

Q Okay. Was that person using oxygen?

A I don't recall. I don't recall whether there was another person in fact. I can find that out, but I don't recall.

Q You don't know?
A I don't recall.
Q Did you supervise this?
A I was not physically present, no. This was the type of test that I would normally ask them to perform and --
Q Who did you ask to perform it?
A Capt. Dixon.
Q So you asked him to perform it?
A That's right.
Q Is he a physician?
A He is not.
Q And so just describe -- well, then you don't know really what was done other than what Dixon told you, is that correct, sir?
A That's correct. I know what I would expect him to do.
Q I understand that.
A Right.
Q We all hope that that is what happened. But, you don't know that is what happened?
A Well, within the parameters that were outlined, I think that I could say for certain what was done. Yes.

Q But only what Dixon told you?

A I was not there.

Q Can you tell me who else was there in addition to Dixon?

A I cannot at this time. I cannot tell you, but we do have records.

Q All right. When was this done?

A This was done in July of this year.

Q Can you tell me the date?

A It was of my first meeting with Mr. Dubuc.

Q Was Mr. Dubuc there?

A At the meeting?

Q At the test.

A He was not at the test. No.

Q Can you tell me the date that this data manipulation was done?

MR. DUBUC: I beg your pardon? The what?

MR. LEWIS: It is called the data manipulation, Mr. Dubuc. I am just reading what it says. I'm not trying to characterize it.

MR. DUBUC: All right.

BY MR. LEWIS:

Q On Exhibit D1222 it says data manipulation.

A. It was done either that same day or one of the -- the following day or a little bit after.

Q. Shortly thereafter?

A. Right.

Q. Can you tell me approximately when that is?

A. Approximately when?

Q. Yes, sir.

A. Within a day or two after the date the test was run.

Q. Well, I'm just trying to find out when you met with Mr. Dubuc or the test, either way, I'm just trying -- would it have been early in July?

A. I think it was in the middle of July.

Q. Middle of July. All right.

You have variable names and it reads time, altitude and 02 sat, which I presume is oxygen saturation?

A. That's correct.

Q. And so where it says varible number 1 on the second page, that means time, is that correct, sir?

A. That is time, yes.

Q. And number 2 is altitude?

A. Number 2 is altitude.

Q. And how long was the subject at 23,424 feet?

~~A At what altitude?~~

Q How long was he there?

A At what altitude?

Q 23,424 feet, sir.

A Okay. It looks like from a point five minutes until sometime between point seven and one point five five minutes.

Q How long was the subject at 5,000 feet?

MR. DUBUC: 5,000 feet?

MR. LEWIS: Yes. It looks like that is what it says.

THE WITNESS: He was there -- I can't tell you the exact length of time he was at 5,000 feet.

BY MR. LEWIS:

Q It is not contained here, sir?

A It is not. No.

Q All right. Are these all of the records on the test?

MR. DUBUC: These two exhibits?

MR. LEWIS: Yes.

THE WITNESS: I don't know. We may have other records. I could check.

MR. DUBUC: For example, what?

THE WITNESS: We usually carry -- keep profiles of the exact flight profile for the entire flight so we may in fact know how long --

BY MR. LEWIS:

Q But that is not here?

A That is not on here. No. What I did is I gave him the data which I had from the MADAR and asked him to run that. I think that he would have to be at 5,000 feet for some period of time. I suspect for more than three tenths of a minute, but --

Q But that is all it says here, is that correct, sir?

A That is correct. This is from the time that he actually began the experiment at 5,000 feet.

Q What is varible number 3?

A It is oxygen saturation.

Q And how was that done?

A By using an ear lobe oximeter.

Q What is an ear lobe oximeter?

A It is a device which you can attach to the ear, using a sensor transducer, gives a digital read-out of the oxygen saturation.

Q So from the document that you gave us, you can't tell at what -- the length of time he was at 5,000 feet, is my understanding correct?

A That is correct.

Q And then where it says OBS, what does that mean?

A Observation.

Q How was that recorded?

A OBS? That is just the first observation, data points.

Q I am just saying how would the data points report it? I mean, you have, for example, data point such and such and then you have certain variable 1, 2, and 3. I just wanted to know --

A I am not sure what your question is.

Q Well, tell me what a data point is.

A Oh, a data point is time, altitude, and oxygen saturation. To the first time that those were measured, that is observation, OBS 1.

Q So you're talking about oxygen saturation in the body of Capt. Dixon, is that right?

A That is correct.

Q So if we look at data point 13, for example, we'd see an altitude, is that correct -- oh excuse me. That is a time point, right?

A Variable 1 is time point, yes.

Q Yes, sir. That is a time point and then an altitude and then oxygen saturation, is that correct?

A That's correct.

Q All right. Where does it say that there was an explosive decompression here?

A Where does it say?

Q I mean, I don't -- is there any part of Exhibit D1222 that suggests there was an explosive decompression at such and such a speed?

A He did at the maximum speed at which our chamber would allow which would be --

Q I'm just trying to find out where it says that on there.

A It doesn't say that. What I asked him to do was run the data points, which I gave him.

Q Did you suggest the speed?

A I told him as rapidly as we could do it. I asked him if he could do it in one second or less and he said that we could not, that it might take one to two seconds approximately.

Q So, none of this was done ata third of a second?

A Not a third of a second.

MR. DUBUC: A third of a second?

MR. LEWIS: Yes.

Was any of it done less than one second?

THE WITNESS: I do not believe that we can do it in less than one second. I believe it is one to two seconds.

BY MR. LEWIS:

Q When you say one to two seconds, that isn't very precise, as I understand science and can you tell me with any precision, sir, what speed it was done?

A. One to two seconds could be very precise.

Q I guess it can.

A. Perhaps, not for your purposes here. I can't give you the exact speed with which the decompression took place. It was as rapidly as we could do it, which is a very quick time, and we do in fact use it to simulate explosive decompression.

Q Well, one of the elements in explosive decompression at least as I have understood it, the factor is speed.

A. Speed.

Q That can be very significant, can it not?

A. It can be, yes.

Q What speed was the explosive decompression in this case?

A. I believe I answered that.

Q When I say this case, I am not -- you will have to forgive me. I am not very precise myself. I am speaking of in the actual event.

A I don't -- I have read, but I don't recall the specific numbers. I believe it was less than one second.

Q It was significantly less than one second, wasn't it?

A I believe it was less than one second. I don't recall the specific number.

Q That is the factor that may be important, isn't it? Speed?

A From the terms of the hypoxia, I don't think so.

Q Or the syllogistic of facts?

A I don't think so.

Q But in any event, the simulation that you did here did not precisely duplicate the conditions on the aircraft, is that it, as far as the speed of the decompression?

A That is true.

Q All right.

A Although it certainly is, I think, within acceptable tolerances.

Q I understand that. I am just trying to find out whether it was exact or not.

A. Well, I'm sure we could get into a discussion as to what is exact and how accurately you could with a ruler, but --

Q. Well, in the measurements of atoms , for example, what might be quite acceptable to the carpenter is truly not acceptable to the physicist, isn't that so?

A. That's true.

Q. So it depends on the task, isn't that right?

A. That's true.

Q. So then it would depend upon, I guess, you experts to decide what is and what is not precise under these circumstances?

A. I believe this is acceptable to the test.

Q. All right. Now, may I see the other one that you did? Thank you, Doctor.

What is DD1223?

A. This was a case of decompression from 5,000 feet to 23,500 feet and remaining at that altitude.

Q. For how long?

A. About five and a half minutes. I'm sorry, ten minutes. No, I'm sorry. Just a moment. Let me just verify what we have here.

It was for five and a half minutes. There are a number of different reports here and I had to check to be sure which one I had.

Q In variable 1, it is time. Variable 2 is oxygen saturation?

A That is correct.

Q And you tested the oxygen saturation and this is again with Capt. Dixon?

A That is correct.

Q You seem to have a lot more things than I have. Are there different --

MR. DUBUC: Well, let's state for the record that Mr. Lewis, you have received copies of these exhibits.

MR. LEWIS: I have 1223 right here.

MR. DUBUC: They have been reviewed and marked in the pretrial conference and whether or not your copy that has been given to you is complete, I have no way of knowing.

MR. LEWIS: I will find out by asking to see his.

MR. DUBUC: Well, that's fine. You just looked at his a couple of times.

MR. LEWIS: Well, I'm going to look at it again.

MR. DUBUC: I don't think we can be held to be accountable for your xeroxing process.

MR. LEWIS: I didn't ever ask you to do that, Mr.

Dubuc. He has got 1224 and 1225 and 1226.

MR. DUBUC: So, they are different exhibits.

MR. LEWIS: Pardon?

MR. DUBUC: They are different exhibits.

MR. LEWIS: I said that. That is the only point I am making. They're not 1223.

MR. DUBUC: But you have 1224 and 1225.

MR. LEWIS: I understand that, Mr. Dubuc. I am asking the gentleman about 1223.

Are these others a part of 1223, the documents that you have there, 1224 and 1225?

MR. DUBUC: Just look at them and tell him what you have got in your hands.

THE WITNESS: I've got 1222, 1223, 1224, 1225 and 1226.

BY MR. LEWIS:

Q Now, are these other schedules, 1225, for example, and 1224, just another way of presenting the same data that we have just talked about?

A That is correct.

Q They are not different tests?

A No, they are not different tests.

Q When did you give copies of this to Mr. Dubuc?

A. At the Saturday's seminar where the experts gathered.

Q. This was sometime in the middle of August?

A. Yes, sir.

Q. Did he know of the existence of this before that time?

A. I don't know.

Q. Did you tell anybody that you had run the tests in July?

A. I don't recall whether I told anyone or not. I don't believe that I told him, no.

Q. Did Mr. Dubuc ask you to do these tests?

A. At our first meeting, we asked whether it could be done or not and I, in fact, asked that it be done.

Q. So is the answer to my question yes?

A. What was your question again?

Q. Did Mr. Dubuc ask you to do this or was it a product of your conversation with Mr. Dubuc?

A. No. I volunteered to do this because I was actually curious myself to find what the numbers were. I would not say that he asked me to them.

Q. But you did it as a result of your conversation with him and so --

A That is correct.

Q -- for his use, is that correct?

A That is correct.

Q All right. I notice that you're a lawyer, sir?

A I have graduated from law school, yes.

(Discussion off the record.)

BY MR. LEWIS:

Q Where did you go to school, law school?

A Georgetown University.

Q And have you had occasion to testify before?

A I have.

Q Often?

A Not very often. No, sir.

Q Under what circumstances?

A I have testified by deposition in some cases which I had been directly involved in reviewing case material in the course of work at the Armed Forces Institute of Pathology. I have testified in Court for the government, the defendants in a case in Pennsylvania, and I testified --

Q Can you tell me in what Court?

A It was in Redding. I believe it was in Redding. I don't know what Court.

Q Was it the State Court or Federal Court?

A. I'm sure -- I don't recall. It was many years ago. Ten years ago, I suppose. And I testified by deposition and in -- by deposition in a number of cases for the plaintiff and in Court in one case for the plaintiff.

Q. All right. I am not positive that that came out just the way you wanted it to. How many times for the plaintiff? A number of times you said with the plaintiff?

A. Once in Court and I suppose three or four times by deposition.

Q. These were for the Armed Forces Institute of Pathology or a private consultant?

A. Private consultant.

Q. Are you being paid by Lockheed as a private consultant in this case, sir?

A. I am not.

Q. So you are not consulting for Lockheed in this case?

A. No, I am not.

Q. You are being furnished by curtesy of the government?

A. That's correct.

MR. LEWIS: That is all the questions that I have.

MR. DUBUC: Okay.

MR. LEWIS: Oh, let me -- those are the only two experiments that you did, is that correct, sir?

THE WITNESS: You mean directly as a result of this case?

MR. LEWIS: Yes.

THE WITNESS: We have done other experiments in the altitude chamber.

BY MR. LEWIS:

Q Oh, I am positive of that. I am just trying to identify what you did in this case.

A Right. For this?

Q Yes. For this case.

A This was the information which I asked Capt. Dixon to do specifically because of this case.

MR. DUBUC: But, as he said, he may rely on his other experiences, Mr. Lewis.

MR. LEWIS: I understand that he has probably an extensive background. I am talking about things in this case.

Well, let me just ask a couple of questions. Do you have any knowledge or experience, sir, with respect to babies in explosive decompression situations?

THE WITNESS: Any experience whatsoever? I --

no, I would say I do not have -- I have not run any experiments with babies.

BY MR. LEWIS:

Q Do you know of any tests or other experiments run on young babies in explosive decompression situations?

A Experiments?

Q Yes, sir. Humans, I am speaking of.

A I can't recall any at the moment. No.

Q Do you know of any experiments run by anybody on human babies and explosive decompression situations?

A I can't recall any at the moment.

Q Do you know of any studies of children -- babies in explosive decompression that were not an experiment, that were a phenomena occurred and you investigated?

A I understand that there have been babies aboard airlines that have undergone decompression. I can't cite to you the specific cases.

Q Do you know of any published studies on them?

A I think they probably must have been published because I think that I recall reading, but I do not recall where and it has not been recently that I have read this material.

Q You're not relying on any of that in your conclusions in this matter, are you?

A. Well, I think in my experience I rely on a broad basis.

Q. I understand that. But, would you be willing to furnish us with whatever articles you have on studies on explosive decompression on babies?

A. (Indicating in the affirmative.)

Q. Thank you. Now, is Capt. Dixon a regular volunteer for decompression experiments?

A. That is his normal duty. He is in fact in charge of operating the altitude chamber facility. Part of his normal duty is he gives training in decompression and runs experiments, projects related to the altitude chamber.

Q. How long has he been doing that, prior to this July test?

A. Let's see. He has been working for me for approximately three and a half years. Before that, at other altitude chambers, I don't recall exactly how long he has been in the Air Force. I think perhaps another three years before that.

Q. So he has been subjected to numberless explosive decompressions prior to this particular experiment?

A. He has undergone decompression, yeah.

Q Can you give me any idea of the order?

A How many times?

Q Approximately.

A I could not.

Q But it is on the order of many, many, isn't it?

A I would suspect it probably has not been many many because his job is essentially as a supervisory and instructor role.

Q Do you know how many?

A I do not know how many. Certainly in the last three and a half years, it has not been many. In fact, this may be the only one in the last -- well, I would have to be guessing as to how many.

Q Do you have any approximation?

A I would have to approximate a small number.

Q Does he have a lot of experience in the altitude chamber? Does it everyday?

A On a regular basis.

Q As a regular basis?

A As a regular basis, yes.

MR. LEWIS: That is all of the questions that I have.

(Thereupon, at 3:15 o'clock p.m., the taking of the instant

CERTIFICATE OF NOTARY PUBLIC

COMMONWEALTH OF VIRGINIA ....)

I, CLAIREEN M. HOLMES, the officer before whom the foregoing deposition was taken, do hereby certify that Dr. Robert R. McMeekin, whose testimony appears in the foregoing deposition, was duly sworn by me, a Notary Public in and for the Commonwealth of Virginia at Large; that the testimony of said witness was recorded by me by stenotype and thereafter reduced to typewritten form under my direction; that said deposition is a true record of the testimony given by said witness; that I am neither counsel for, related to, nor employed by any of the parties to the action in which this deposition was taken; and, further, that I am not a relative of or employee of any attorney or counsel employed by the parties hereto, nor financially or otherwise interested in the outcome of the action.

Claireen M. Holmes

Notary Public in and for the
Commonwealth of Virginia

My Commission expires: February 18, 1985 deposition ceased.)

____
Signature of the Witness

SUBSCRIBED AND SWORN to before me this __________ day of ________________, 1981.

____
Notary Public

My Commission expires:

Mc. ekin Dep. Exh. 1

ACCIDENT RECONSTRUCTION FROM ANALYSIS OF INJURIES

by

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SUMMARY

Careful analysis of known dynamics of impact in fatal aircraft accidents has led to an enhanced understanding of the pathogenesis of the injuries incurred. From an ongoing study of over 500 fatally injured crewmembers of U. S. military aircraft every year and an analytically oriented research program in which injury patterns are verified by computerized simulation techniques, it has been possible to prepare estimates of injury correlated with both the magnitude and the direction of the applied decelerative forces.

Conversely, when an accurate tabulation of postmortem injuries is correlated with measurements of the path of the aircraft after it strikes the ground, the dynamics of impact may be deduced. This process is invaluable for accidents that occurred without witnesses or survivors and in which crash damage to flight instruments or the absence of flight-data recorders makes calculation of impact kinematics difficult.

Skeletal injuries, particularly vertebral compression fractures, lacerations and contusions of viscera, aortic tears and lacerations, and cutaneous contusions caused by compression of harnesses and seat belts, are important factors in determining the direction and magnitude of the deceleration vector.

INTRODUCTION

Aviation pathology has great potential value in the clarification of those events that precede, occur during, and follow an aircraft accident. The tissues of the human body, with their plasticity and diversity, can serve as positive documentation of both the magnitude and direction of the forces generated, of the presence of toxic hazards before the accident and of the occurrence of fire and structural frag-

In the past, emphasis has been put upon a detailed structural analysis of the airframe and engines in order to determine the dynamics of an airplane accident. There are at least two reasons for this. In the process of development and construction of airframes a great deal has been learned concerning the static and dynamic properties of the various components of the aircraft. This information can be combined with an analysis of the wreckage in an attempt to reconstruct the accident.

More important has been the tendency of the pathologist investigating an aircraft accident to confine himself to the simple determination of cause of death and identification of the deceased. This has stemmed in part from the outgrowth of aviation pathology from civilian forensic pathology and in part from the impression on the part of both physicians and engineers that there is little else of value for the aviation pathologist to offer.

In recent years, the design of ejection seats, of active and passive restraint systems, and of generally improved airframe crashworthiness has led to an explosion of information on the static and, to a lesser extent, the dynamic properties of various human tissues as influenced by a variety of forces. Pioneers in the dissemination of this information have been the organizers of the annual Stapp Car Crash Conference and the Federal Aviation Administration, which has put out various publications on it. There has also been an increase in the number of trained forensic pathologists with an interest and background in aviation as well as an ability to talk to and work with the technical members of a board investigating an aircraft accident. The result of these changes has been an enhanced ability of the aviation pathologist to use the information he obtains from postmortem anatomic and toxicologic studies not only to determine the cause and manner of death but also to assist the investigation board in determining the cause and manner of the accident.

PLAN OF SUGGESTED PROCEDURE

One of the earliest important uses of medical information in clarifying the physical circumstances of an accident was in the now-famous series of Comet disasters, which occurred over 20 years ago (4, 5). These accidents demonstrate the importance of the aviation pathologist's or flight surgeon's possessing a sound method for collecting and interpreting this information. What we will emphasize in this paper is such a technique. We will then present both our experience and the information found in a review of the literature about the magnitude of forces sufficient to produce the most common injuries seen in personnel who have been injured or killed in aircraft accidents.

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*The opinions or assertions contained herein are the private views of the authors and are not be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

Before starting out, it is always helpful to obtain a preliminary impression of the operational circumstances of the accident. There is little value in doing a "blind" autopsy. In forensic pathology it is dangerous, and in aviation pathology it is next to worthless. There is usually some indication as to the cause or at least the general circumstances surrounding an accident. Bad weather with turbulence might indicate an in-flight structural failure or loss of a rotor blade. Approach accidents may be associated with wind shear. In a tactical training environment, helicoptor accidents are associated with misjudged "pop-ups" or NOE (nap of the earth) flight maneuvers.

The best way to obtain such a preliminary evaluation is by conducting a personal inspection of the wreckage. Frequently those details that are most useful to the aviation pathologist in understanding the various fatal injuries are thought to be unimportant by the structural analysts. If the injuries are predominantly right sided in the occupants of a helicopter that has impacted on its right side, the presence of a single severe crush injury to the leftside of a victim might prompt a search for some other mode of structural failure. It is often of great value to visit an intact model of the involved aircraft. The location and type of controls, the colored markers on instrument dials, the location and configuration of rudder pedals, and the type and location of occupant restraints will give the pathologist a much greater degree of confidence in his opinions about the production of various injuries. Unfortunately, the logistic requirements and restricted time under which the aviation pathologist often operated may limit the accessibility of the scene of the accident to him. Similarly, it is unusual for him to be present when the bodies are removed from the wreckage.

The actual postmortem examination must be thorough, searching, and unhurried (6, 7). It is of primary importance not only to catalogue all of the injuries but also to arrange them into meaningful groups and patterns. The best aid for this is the use of diagrams so that a multiplicity of injuries can be seen at a glance. When all of the external and internal injuries have been tabulated, they should be grouped into injuries that are produced by deceleration as opposed to those produced by impact or other mechanisms. The recognition of these acute impact injuries (8) as opposed to those injuries produced by deceleration may prove difficult, and it is well to remember that decelerative forces are always transmitted to the body via some restraining mechanism (harnesses, seat backs, hardpans) and that, if severe enough, these may mimic impact. Trauma to the body from impact shares some of the features of deceleration injuries (particularly in the case of falls from heights), but careful examination of the injury, in conjunction with study of the circumstances, will assist in their differentiation. Impact-type trauma is often associated with tracts leading inward; decelerative injuries are often associated with injuries that begin within the interior of the body. With the increased protection being afforded to the head by means of helmets, restraints, air bags and energy-absorbing panels, visceral integrity and fractures of the cervical spine represent the limiting factors in many crash situations.

X-ray films are of great importance in understanding the dynamics of an aircraft accident. Bearing in mind that the interiors of the skull, thorax, abdomen, and pelvis will be viewed in the course of the autopsy, the aviation pathologist will optimize limited resources by concentrating his attention on procuring roentgenograms of hands, feet, proximal extremities, and the spine. "Scout" films may be shot through a body bag before attention is focused upon a particular detail. This helps to reduce contamination and excessive soiling of radiographic facilities, which are usually used for living patients.

After the injuries have been divided into impact vs. decelerative types and these further subdivided by type and location of injury, it is important to determine the magnitude and direction of the forces necessary to produce them. This subject is later treated in detail.

It is useful to search out an injury or pattern of injury that does not fit in with the others present on the body of the deceased. Even more useful is the discovery of an unusual pattern among the patterns found on the many victims of the same accident. This "odd man out" theory was first proposed by Mason (9) in investigating the fatalities resulting from a bomb explosion aboard an air carrier transport. It also has significance for the investigation of military aircraft accidents.

A U. S. Army helicopter collided on its left side with a rocky hillside. Those crewmembers seated on the left side of the aircraft suffered severe crushing injuries on their left sides. The aircraft commander, in the front left seat, also had a hatchet-like avulsion of the posterior portion of the right temporal and occipital portions of his skull. This was later shown to be the result of a strike by a main rotor blade that was separated by mast bumping during severe turbulence in flight.

When the collection of medical data is complete, the calculation of the magnitude and direction of forces made, and the preliminary details about the technical circumstances of the accident obtained, a theory should be formulated that will be as compatible with as many of these features as is possible. Then it is necessary to determine whether this theory is compatible with any new information that has been uncovered in the progress of the investigation. It will often be necessary to revisit the wreckage or scene of the accident if there appears to be a conflict between the medical evidence and the initial impressions of the engineering analysis. The medical evidence may need reinterpretation, or the damage to the aircraft may have to be viewed in a different light.

It is to be hoped that next there will be a gradual refinement of these two aspects until a common working theory has been proposed. The primary contribution that the aviation pathologist can make to the understanding of an accident is an interpretation of the dynamics and sequence of events in an accident that has been independently reached. When both medical and engineering hypotheses are similar they reinforce each other, and when different they focus attention on details that otherwise may have been misinterpreted or overlooked.

CALCULATION OF DECELERATION FORCES

When an impulse is applied to a structure, the energy of impact is distributed throughout that structure in a manner that is dependent upon (a) the magnitude of the impact, (b) the duration of its application, (c) the area over which the force is applied, (d) the immediate underlying physical characteristics of the structure and the impacting body, and (e) the availability of pathways for conducting this energy away and dissipating or redistributing it in the surrounding tissues.

The energy of impact is a function of mass, velocity, acceleration, and time. These relationships may be summarized in Equation 1:

$$\text{Eq-1.} \qquad E = \frac{MV^2}{2} = \frac{FV^2}{2A} = \frac{FAT^2}{2}$$

where E is the energy of impact, M the mass, V the net change in velocity occurring during the deceleration, and T the duration of the impulse. The force of impact, F, is defined as:

$$\text{Eq-2.} \qquad F = MA,$$

the product of mass and acceleration. At 1 g the condition of rest, mass may be continually added to a structure at a point of application until it deforms to a predetermined extent or until it suffers structural failure. Such a static condition does not closely correspond to the dynamic conditions that occur in accident trauma, where the forces are applied over short periods of time on the order of milliseconds. It is obvious that under static conditions there has been a maximal opportunity for the load to be distributed throughout the structure being stressed (10).

In all of the tissues of the body, the duration of the impulse has a dominating effect upon the type of injury seen. For impulses that last on the order of 500 msec. or longer, injuries are produced by (a) the direct action of restraint systems and (b) the differential movement of various body organs. Fractures of the clavicles and ribs, abdominal contusions, pancreatic hemorrhage (11), and perhaps capsular tears of the liver and spleen are examples of the first mechanism. Intimal tears of the aorta, tears of the renal arteries, and anterior cardiac contusions are examples of the latter. These are due essentially to displacement in the horizontal plane, since vertical changes of velocity are usually accomplished in much shorter periods of time and within shorter distances.

Between 25 and 500 msec., the duration of most crash pulses, injuries due to both horizontal and vertical decelerations are seen. Injuries present during this time frame are due to decelerative forces acting on the body applied by restraint systems, impact against cabin structures and/or the ground, and the effect of failure of restraint systems. Following such a failure, injuries are produced that are caused by the mechanism of failure itself, impact against cabin structure while partially restrained, and complex patterns of injuries as the occupant and aircraft rapidly come to a halt in random and unpredictable attitudes. Because of this unpredictability, it is very difficult to use injuries produced after restraint failure in the calculation of force vectors unless the time intervals are so short that one may be reasonably sure that no significant movement occurred. Severe tears and disruption of the viscera, multiple comminuted fractures of the extremities, compression fractions of the vertebrae, and evisceration and avulsion of internal organs are seen in this range of injuries.

Provided that the total energy that must be dissipated is small enough, the rate of onset of acceleration is not important, but even at a slow walk a 150-lb. man possesses the 600 to 800 ft-lb of energy necessary to fracture the nasal bones and at 10 miles per hour there is enough kinetic energy present, if concentrated over a single area, to result in severe injury or death.

Impulses of extremely short duration produce injuries that are quite different from the two preceding types. These would be rates of onset in excess of 50,000 g/sec. and lasting less than 10 msec. In this instance the impulse is over and the kinetic energy absorbed before the individual components of the body have time to respond. The high natural frequency of these short-duration impulses are so much greater than the natural frequency of the body or of individual organs that the energy is absorbed and then released diffusely. If great enough, the effect of this diffusely absorbed energy is widespread disruption of structure. It is best seen in high-speed jet aircraft accidents in which that portion of the aircraft in front of the occupant has been completely obliterated and the individual strikes the ground with a velocity very little changed from his initial speed.

Such "impulsive" impacts may be recognized pathologically by the presence of extensive shards of skin, often representing the entire integument of the thorax or abdomen, split down the front or back and devoid of the viscera and skeleton it once contained. Calculated g forces for such impacts are of the order of 600 to 1,000 or greater and represent energy levels of 1 to 3x106 ft-lb. This is the situation of a 150-lb. man traveling at about 200 ft/sec. and assuming a stopping distance of only 1 foot. At the upper part of this range, complete and uniform destruction of the entire body becomes the rule, although it is rare not to discover at least a few fragments.

The mass term of Eq-1 and Eq-2 refers to the mass of the occupant (or portion of the occupant) and not the mass of the vehicle. There are structures that effectively add to the mass, however, and thus to the energy of impact the life-support equipment of the occupant must absorb. This is primarily the mass of the seat back and that of the restraint system itself. These formulas may also apply to any individual part of the body that may move quasi-independently of the rest of the body. This primarily applies to the head and extremities, organs that pivot at only one end. For other body segments, energy is not only being absorbed by the segment being stressed but may be transmitted and absorbed by adjoining body segments. This depends upon the duration of the impulse and the orientation of it as applied to the segment in question.

Because of its large mass the vehicle in a severe accident contains an energy for dissipation that is vastly greater than that contained in the bodies of the occupants. It is the goal of good crashworthy design that this energy be dissipated in controlled deformation of the structure, maintenance of a habitable cabin volume, and a pattern of breakup that allows a decrease in mass without endangering the occupants. At all costs this kinetic energy should not be transmitted to the occupants or to their seats by overly rigid structure.

The area over which the force is applied has its most obvious application in the advocacy of rearward-facing aircraft seats. With this arrangement the forces are distributed over the entire area of the back of the person. The width of the webbing in restraint harnesses will insure that the decelerative forces that are applied to the thorax are not concentrated over individual ribs, which would cause fractures and cardiac lacerations. This demonstrates the need for the aviation pathologist to be familiar with the restraint system in use when he is interpreting a particular injury.

The type of tissue at the point of impact and the composition of the impacting material are important in attenuation of crash force. There may be an initial opportunity for considerable absorption of energy before transmission to vital organs. The types of tissue most efficient in this respect are the large muscular and fatty masses of the abdomen and buttock and fascial planes such as that of the tensor fascia lata. Compression of these tissues may increase the effective stopping distance and significantly diminish peak _g_ forces. For a similar reason there has been much recent interest in energy-absorbing structural panels (12).

Both the tissue and the impacting surface may flatten out during the impact and spread the force over a greater area.

The mechanism for initially redistributing the energy of deceleration is by transmission of this energy through bone (femoral forces transmitted to the pelvis via the acetabulum), tendons, and muscles. A demonstration of this effect is the dramatic reduction of peak _g_ forces in the head and particularly in the neck that can be accomplished by simply tensing muscles and "opening up" pathways for force transmission and, hence, attenuation.

The direction from which an impulse originates will also determine the availability of other dissipative pathways. A force applied perpendicular to the long axis of the femur will cause more damage than one applied along its axis. In the latter circumstance part of the energy is dissipated by the transmission of an axial force to the bony pelvis and the stout muscle groups on the back and on the lateral aspects of the trunk. A knowledge of the usual seating posture of a particular crew station is important in interpreting injuries, particularly of the pelvis, trunk, and lower extremities.

It is clear, then, that when attempting to evaluate the degree of force that produced a particular injury and from this calculating the impact conditions that caused it, the aviation pathologist must search out information in the five categories mentioned.

The magnitude of the impact can be determined by careful gross examination of the tissues. X-ray films often provide a clearer impression of the degree of bony trauma than does dissection and do not reflect postmortem changes.

The duration of the impact may be ascertained from the injury in an affected part as well as from an engineering estimate of the velocity of impact, the impact attitude, and a rough estimation of stopping distance. With this information, Eq-3 gives an estimate for the average g forces in a crash:

$$\text{Eq-3.} \qquad Am = \frac{V}{2D}$$

where Am is the average deceleration (in ft.sec.-2). It is best to assume a triangular deceleration pulse, and in that case the peak g force. Ap, is equal to twice Am. Under these conditions the time (t) required to completely dissipate the velocity change V is given by

$$\text{Eq-4.} \qquad t = \frac{V}{Am}$$

The rate of onset of acceleration (J = "jerk," the third derivative of displacement with respect to time) is given by

$$\text{Eq-5.} \qquad J = \frac{(Ap)\ (t)}{2}$$

The area of the impact and its composition with respect to attenuation of injury may be ascertained by careful dissection, particularly of areas of subcutaneous tissue that border obvious contusions and lacerations, and by a thorough briefing of the types of life-support equipment present and their apparent utilization. Finally, some familiarity with seating arrangements and, if available, premortem anthropometric measurements of the deceased may aid in estimating the orientation of the decelerative forces.

MODIFYING FACTORS AND IMPACT INJURIES

Factors that may modify impulses and decelerative forces should be mentioned. Shoulder harnesses and seat backs attenuate deceleration in the -Gx direction. Items of importance in this instance are (a) the degree of belt preloading, (b) the stress/strain characteristics of the webbing, (c) the amount of free travel before inertial lockup occurs, and (d) the ultimate failure limits of the belt and the belt attachments. If the occupant is facing to the rear, the seat back will attenuate an impulse in the -x direction. In this case factors of importance are (a) the nature of the padding and depth of the seat back, (b) the interactions between the back and other energy-absorbing components of the seat, and (c) the ultimate failure limits of the back.

Modification of crash impulses in the ±z direction are obtained by (a) placing padding between the seat bottom and the hardpan, (b) the stroking and other energy-attenuating properties of the supporting structures of the seat's tiedown, (c) belts in a multipoint harness system that envelop the shoulders, lower torso and thighs, and (d) by straps extending from the seats to the ceiling and lateral walls of the vehicle's cabin. Lateral ±y attenuations of impulse are created by (a) lateral components of multipoint seat harnesses and (b) surrounding cabin boundaries.

Apart from decelerative trauma, impact may be sustained by (a) impact with the ground, (b) contact with the disintegrating structure of the aircraft, (c) laceration and penetration of the head, thorax, and extremities by control sticks and instrument knobs, (d) strikes by propellers, turbine blades, and helicoptor rotors, (e) a hazardous postcrash environment in which fire, carbon monoxide, and other toxic products of combustion are present, and (f) artifactual changes in the bodies caused by the unwitting interference of rescue personnel or predators or the effects of weather or postmortem changes.

Ground impact may be recognized by a linear pattern of abrasions and the presence of dirt and debris ground into clothing and wounds. Bodies may be found still strapped into their seats, the entire seat-man assembly having been hurled out of the aircraft. When bodies are found scattered in a linear fashion under the reconstructed flight path of the aircraft, in-flight structural failure should be suspected. If a detailed seating plan is available, or if family groups can be identified, the pathologist may be able to give some clue to the precise sequence of the structural failure that occurred. If impact has occurred from an altitude sufficient for the released bodies to reach terminal velocity, extensive fractures of the skeleton will be present. These will have either a widespread distribution or, if the ground strike occurred in a particular attitude, they may be limited to a portion of the body. For example, in a rapid, partially controlled parachute descent, if the feet initially strike the ground there may be collapse of the acetabulum with the femoral heads driven into the pelvic cavity. In assessing such injuries, particular attention should be paid to the presence of any partially deployed survival equipment that may have attenuated the ground impact and to any features of the ground itself that may have significantly altered the conditions of impact.

Contact with the disintegrating structure of th aircraft can usually be recognized by the random introduction of metallic fragments into the body cavity. It is important to have someone present at the autopsy who will be able to identify this debris with reference to its original location within the aircraft. The pattern injuries produced by impact with control sticks and instrument knobs on the instrument panel have long been recognized as being of value but the presence in the depths of wounds of the colored "tapes" used as markers on the faces of instruments may also be helpful.

Propellers, rotor blades, and turbine blades produce a distinctive combination of blunt force and chopping injuries, causing avulsion of body parts. Particularly in cases of mid-air collision involving propeller-driven aircraft, the bodies should be examined for evidence of propeller strikes. The wounds should be inspected for traces of paint, fragments of anti-ice equipment, and other mechanical devices that may be associated with a particular propeller assembly.

These impact injuries of nondecelerative type, when properly recognized and catalogued, and when the various factors that may cause their production and modification are taken into account, will provide valuable information about the initial stages of the accident and the ensuing sequence of events that are not strictly related to occupant kinematics.

RESPONSE OF HUMAN TISSUES TO DECELERATION

It is impossible to extensively review the vast literature that has accrued since World War II on human response to impact. Recent reviews are those of Channing (13), Snyder (14), and AGARD (15). Much of the literature on impact injury describes various models for the understanding of the mechanism of injury production. In the following sections we shall concentrate on that literature that sets threshold levels for specific injury. It is worth noting that these levels vary widely among different authors. This variation results from (a) a lack of uniformity of experimental design, particularly with respect to the measurement of loading and the nature of the impacting surface, and (b) a wide variety of experimental subjects, such as assorted anthropormorphic dummies, cadavers, human volunteers, animals, and computer programs that simulate impact and injury.

The information that follows on injuries to various organs was collected from the literature and also represents the experience of the Aviation Pathology Division of the Armed Forces Institute of Pathology, where over 500 aircraft accident fatalities are reviewed and coded each year.

A consideration of the injuries present in the deceased and a knowledge of the various thresholds needed to produce them will furnish a range, usually clustering around a lower limit, of forces for a particular injury. It is necessary to collect a number of such ranges or lower limits in order to narrow the estimation of force and deceleration that were applied to the body as a whole. An accident may produce a "total body" deceleration of only a few g yet be fatal because of a localized area of higher values. It is similarly important to note and tabulate what injuries did not take place, as a means of fixing upper bounds on the accident forces and decelerations.

Abdominal Viscera. Much of the literature on visceral injuries has attempted to quantify and correlate the lesions produced with the intrinsic stress/strain properties of the tissues (16). It is difficult to translate this knowledge into information about deceleration after impact. Hepatic and splenic injuries are those most commonly seen (17). Mays (18) gives an energy value of 285 to 360 ft-lb as being sufficient to cause capsular tears and bursting of the liver. If the victim is wearing only a simple lap belt, peak decelerations of 25 to 40 g are sufficient to cause hepatic injury. As the complexity of the restraint system increases and the load is distributed over a wider area, this "total body" deceleration threshold for abdominal injury increases to the neighborhood of 100 g.

Weis and Mohr (19), using x-ray cinematography, studied visceral movement in human volunteers subjected to a velocity change of 7ft./sec. over a duration of 7.5 msec. They noted a net axial movement of the liver of approximately 1-3/4 inches. In a somewhat similar study, Kazarian (20) found that a -Gx pulse of 120 g would produce hepatic capsular tears in monkeys. At the lower end of these ranges the principal tears are found at and near the suspensory ligaments and at the hilum, another relatively fixed point. The superior surface is relatively spared, no doubt because of the cushioning effect of the diaphragm.

At levels of 150 g and higher, bursting and disruption of the hepatic parenchyma are seen. Since the capsule of the liver constitutes its major source of strength, it is probable that disintegration proceeds rather rapidly once it is broached.

Comparable values for the spleen, the second most commonly injured abdominal organ, have not been published. Pancreatic injury from seat-belt compression has been reported (21). The bowel can have a number of injuries. At lower levels, 25 g we begin to see contusion at the roots of the mesentery. Contusions from seat-belt compression are not uncommon, but evisceration and loss of integrity of the anterior abdominal wall usually occurs before there is "flailing" of loops of bowel and loss of continuity. This probably occurs at levels higher than 150 g. In applying any of these considerations to abdominal trauma, care should be taken that the injuries were not produced by other mechanisms such as fracture of the ribs or by penetration of the abdomen by portions of the aircraft during structural breakup.

Thoracic Viscera. The injuries most commonly seen in this site are those of the lungs, heart, and great vessels. The same mechanism that causes hepatic and splenic injuries applies to the lungs. Subpleural hemorrhages, similar to hepatic capsular tears, are seen at about the same level of deceleration. Because of the increased elastic tissue component of the lung there is less of a tendency for complete disruption. Amputation about the hilum is frequently noted following high-speed impacts of greater than 200 *g*.

Injuries to the heart may be caused by laceration by broken ribs, forceful thoracic compression, or by bursting from increased intraluminal pressure (21, 22). Although static values of the stress/strain characteristics of the myocardium are available in the literature (23), the dynamic properties have been less extensively studied. Epicardial contusions caused by direct compression can be produced at a rather low level of applied force if the sternum is depressed sufficiently. They are a not uncommon sequella of manual compression during cardio-pulmonary resuscitation. If an adequate restraint system is present, the amount of energy needed to produce this injury is of the order of 3,500 ft-lb applied over 20 to 30 msec.

The mechanical properties of the aorta vary widely with age (23) and with pre-existing disease. Intimal tears caused by violent motion of the heart about relatively fixed attachments are usually transverse in shape, indicating a mechanical rather than a hydraulic origin (24, 25). Given an adequately restrained thorax, such tears are first noted at levels of deceleration approaching 40 to 60 *g* and proceed to through-and-tears when the values reach a range of 60 to 80 *g*. These particular injuries probably represent the limiting factor in survival at the present time.

Injuries to the tracheobronchial tree are frequently seen, but their mechanism of causation is obscure. Tears are often seen at the point of bifurcation and are more common on the left than on the right (26), possibly because the mass of the heart and ligamentous attachments of the great vessels limits movement. It is not possible to correlate injuries with levels of deceleration from the information in the literature.

Because of their extensive dependence upon the type of restraint system used, their variability in threshold, and the lack of known dynamic properties of behavior under impact, visceral injuries are not the most useful for estimations of crash forces. A major disadvantage lies in the fact that the entire visceral mass is of relatively homogeneous composition, and therefore the direction of applied force is not an important factor in the production of an injury here than in other regions of the body. Since the production of capsular tears in the liver, lungs, and spleen may have their origin in the interactions of propagated pressure waves in the thorax and abdomen, the location of such tears may be independent of the direction of the driving force.

Spine. The injuries seen in the spine vary, depending upon the direction of the impacting force. With purely vertical stresses there is an initial slight twisting movement as the individual vertebrae compress the intranuclear discs and rotate about each other (27). The articular facets engage each other, and this is followed by loading of the intra-spinous ligaments and muscles. Natural regions of weakness in the bony column are C6-7 and T12-L1, where there is a meeting of the reverse curvatures. The facets are quite strong, and failure usually starts at the vertical end plates of the vertebral bodies (28) on the anterior or posterior lip. At an impulse of 20 g collapse of an entire vertebral body may be seen. At values higher than this, disruption of the ligamentous framework of the spine occurs, and at peaks of over 150 to 200 g there may be loss of continuity of the spine and overriding of the fragments. An injury usually accompanying this is transection of the aorta at the same level.

As the axis of application of force changes from the -Gz to the +Gx direction, increased force is applied to the transverse ligaments and facets. There is usually an increased stopping distance in the horizontal plane, however, and other components of the axial skeleton take up the load. Horizontal impulses of greater than 100 to 150 g are necessary to produce severe injury to the lower portions of the spinal column.

The Chance fracture (29), which involves the posterior vertebral arch, the laminae, pedicles, and transverse and spinal processes, is due to extreme flexure of the upper body, as may occur during failure of upper-torso restraints (30). This may be difficult to detect radiologically but can usually be demonstrated by careful dissection and, if necessary, clearing of the specimen. This fracture and minute collapse at the anterior lip of the vertebral body may be among the first lesions seen in the spine.

Begeman et al. (31) studied the loads resulting from g deceleration in the spine. Using cadavers, their test runs on sleds produced g forces ranging from 12 to 16. The loads generated varied from 450 to 1,250 lb. Fractures of the crushing variety were found at L1, T9, or T7 in all of the test subjects. This probably represents a lower limit for the onset of injury. The total duration of these pulses was on the order of 170 msec.

Factors modifying spinal injury include the orientation of the spine at impact, the type of restraints and seat cushions in use, and the presence of pre-existing spinal injury or weakness. Since the total stopping distance in the vertical direction is quite small, minor errors in the approximation of this value will affect the calculated g forces significantly. The wreckage can be examined for vertical deformation and the depth of the gouge in the earth measured. It is important to correct for the slope of the terrain, since this can exert a dominating effect on the final calculation of stopping distance and hence of vertical velocity.

Kazarien *et al.* (32) have presented a detailed analysis of fracture patterns in the spines of both man and rhesus monkeys resulting from +Gz loading. They found that for "impulsive"-type loading (2 msec.) at 800 *g*, there was severe comminution of one or two vertebrae, whereas with increased duration (16 msec) and lower loads (150 *g*), there were only compression fractures of vertebrae, and these spread out over a greater extent. They also determined that the region of greatest probabil iity of fracture was in areas of reverse curvature, and they attributed this to a change in bearing of the articular facets.

Even more important, they warned of the inadequacy of routine x-ray examination in detecting early injury patterns. This has been our experience as well. The earliest signs of failure of the spine are hairline fractures of the articular facets, chance fractures of the neural arch and disruption of the nucleus pulposus. These may be seen with decelerations of as little as 6 to 10 *g* when the rates of onset are in excess of 1,000 *g*/sec.

Extremities. Impact studies have defined the tolerance levels for the human femur (33, 34). Between 25 and 50 *g* there is little or no damage when the impact is perpendicular to the shaft. This experimental situation produces energy levels of 200 to 400 ft-lb, and the duration of the pulses were from 10 to 25 msec. As the duration of the pulse decreased (33), there was increasing damage to the superficial tissue of the leg. The use of embalmed cadavers in many of these studies, however, makes soft tissue injuries difficult to interpret. Between 35 and 75 *g*, hairline fractures of the shaft of the femur were produced as well as severe comminuted fractures of the patella. At these energy levels (400 to 600 ft-lb) pulses of short duration produced severe shattering injuries of the patella; at longer durations there were destabilizing fractures of the tibial shelf and the inferior condyles of the femur.

With levels of absorbed energy in excess of 600 ft-lb, corresponding to applied forces of 2,000 lb extending over a period of 10 to 20 msec., there were severely comminuted fractures of the femur. These correspond to mean accelerations of 75 *g* or greater. Cooke and Nagel (34) maintained the force applied and the energy absorbed essentially constant and varied the duration of the applied pulse. Stress "waves" were observed passing up the length of the femur at the longer durations, and strain gauges revealed considerable afterloading related to the resolution of the bending stresses that had been induced in the bone by the initial deflection.

King *et al.* (35) studied the response of the femur and patella to forces of varying duration and magnitude. They concluded that approximately 1,700 ft-lb for 50 msec. was a conservative estimate of the energy that could be applied to the human femur before fracture. They also concurred that at very short durations- 3msec.-patellar fractures were by far the more important injury and that impulses of this duration would have to be in excess of 2,700 ft-lb before femoral fracture would occur. The actual initial point of fracture--pelvis, femur, or patella--was more dependent upon duration of pulse and degree of muscular and fascial tensing than upon any wide differences in ultimate intrinsic strength.

Once a severe comminuted fracture of the femur occurs, it is probable that this fracture rapidly proceeds to amputation. At the moment of fracture there is a marked plateauing of g forces on the tissue below the break. The considerable energy stored in bending deformation is released to the surrounding tissue by the jagged ends of the bone with ensuing laceration. In addition, the energy of deceleration that had been being previously loaded into the bone is now fully applied to the soft tissues. The skin provides considerable reserves of strength because of its highly elastic composition. It is not uncommon to find cases in which the bone and muscle are entirely disassociated at the point of fracture but the limb remains attached to the body by a partial flap of skin.

Patellar injuries are seen at g levels of 30 to 50 when the onset of these forces exceeds 2,000 to 3,000 g/sec. Even at lower levels, ligamentous tears can cause severe destabilization of the joint, which can prevent egress from an aircraft. The failure pattern of the anterior cruciate ligament of the knee was studied by Noyes et al (36). Significant variation of behavior was noted to be a function of rate of onset of stress and orientation of the stress in relation to the osseous attachments of the ligaments. Three patterns of falure were observed: (a) ligamentous failure, (b) tibial avulsion fracture through the bone underlying the insertion of the ligament, and (c) cleavage of the ligament-bone interface. The load levels for these failures was approximately 225 lb.

Kramer et al. (37) studied the fracture characteristics of the human tibia. Fifty percent of the population studied could be expected to incur tibial fractures when a force of approximately 1,000 ft-lb was applied, corresponding to a deceleration of only 15 to 20 g. Higher levels of tolerance and failure could be expected to exist in a younger military population.

Similar studies are not available for the human arm. From scaling considerations, the same range of figures as seen for the tibia should apply to the humerus, and lower values should apply for the forearm. An additional mode of humeral failure is avulsion through the glenoid fossa caused by violent flailing about the shoulder. The energy level needed to produce an injury of this type seems to be quite high, probably in excess of that needed for fractures of the lower extremities. In the leg it is more common to see amputation through the anatomical neck of the femur than disarticulation. The seated posture may explain this.

Careful examination of the small bones of the hand and feet may give information as to the identity of the pilot at the time of the accident, but the more usual case is for many of the fatalities to have similar fractures. Comparison of these many fractures may be made so as to see whether a single person has an unusual distribution or pattern that may identify the pilot.

Modifying features in extremity injuries are the presence of restraints (as part of the ejection seats), seat posture, and angle of incidence at impact. In particular, off-center forces applied to the upper leg, which produce a rotary motion, are productive of much less injury than direct impact (33), presumably because of the sharing of the load by the ligamentous attachments of the leg and because of the ability of the femur to store considerable amounts of energy in twisting. Flexing of the knee has a similar protective effect.

Head and Neck. It is useful to consider two levels of injury threshold in head trauma: cases with skull fractures and those without. Swearingen (38) studied the fracture thresholds of the various parts of the skull and found that the impacting surface was of the order of 2 to 4 in.+^{2}, nasal bones were fractured at 30 *g*, the frontal eminence of the mandible at 40 *g* the zygoma at 50 *g*, the frontal bone at 80 *g*, and the area of the mandible and maxilla in the region of the front teeth at 100. If the force was applied over 8 to 10 in.+^{2}, the frontal bone could survive over 200 *g* without fracture, and if the entire face was used as a decelerative surface the tolerance was over 300 *g*.

Gurdjian (39) determined that energy levels as low as 35 to 70 ft-lb are sufficient to produce single hairline fractures of the skull. Numerous studies, summarized by Snyder, give the range of loads for frontal and parietal fractures as 1,000 to 1,700 ft-lb (averaging about 1,200) for frontal bone and 770 to 1,290 (clustering about 850) for parietal bone. The minimal value at which failure occurred was about two-thirds of the mean for the respective types.

Provided, then, that fractures and deformations of the skull are not allowed to take place, the head is remarkably resistant to injury. In a follow-up study, Swearingen (40) reported both experimental and accident-investigation data showing that peak accelerations in excess of 400 *g* with rates of onset in excess of 105,000 *g*/sec are survivable provided that the motion is purely translational. Higgens *et al*. (41) offered a similar result with angular accelerations in excess of 1.5x10^5, which translate to a linear acceleration of about 600 *g*.

The large amount of literature on the mechanism of production of intracranial trauma gives a few clues as to the relation between the trauma and the causal mechanism. In the absence of fracture with underlying contusion and laceration of brain tissue, the anatomic evidence of injury consists of subarachnoid bruises and small tears of bridging vessels. Omaya (42) summarized various models of impact trauma to the brain and head, reviewed much of the literature pertinent to this problem, and offered a 50 percent probability of concussion in man when the angular acceleration exceeded 1.1x10^3 radians/sec.$^{-2}$.

Shatsky (43) employed rhesus monkeys and found no parietal fractures at forces up to 390 ft-lb and accelerations in the *g* direction of over 470 *g*, but neurologic injuries associated with intracranial contusions and subarachnoid hemorrhage were common in this group. With forces in excess of 500 lb and decelerations in excess of 500 *g* fractures, first hairline and then depressed, became progressively more severe and were associated with more severe intracranial injury. For occipital impacts the threshold for cerebral contusion was of the order of 250 lb of force with a corresponding acceleration of 640 g. The threshold for fractures and more severe cerebral damage was in the order of 500 to 1,000 lb of force, corresponding to a deceleration of 900 to 1,400 g. Interspecies scaling considerations should reduce these values in man by a factor of about one-half.

In summary, we can say that the onset of anatomic evidence of cerebral contusions requires an average of 300 g when the head is adequately restrained and padded. In fractures of 500 g coup and contrecoup lesions are present. These levels are above those needed for "sharp" limited-area impact of facial bones, which require only 30 to 100 g for fracture. If fracture or plastic deformation of the skull can be prevented, overall head decelerations of 350 to 500 g can be tolerated without serious injury.

Thoracic Cage. In this context we are referring to the ribs and their associated vertebral and sternal attachments and not to the viscera contained within them. Beekman and Palmer (44), using a rhesus monkey as a model, recorded peak forces of 700 lb as producing up to a 3-inch deflection of the anterior thoracic wall. No fractures were observed in this series. Using unenbalmed cadavers, Kroell et al. (45) found "severe" injury with impact forces of approximately 1,000 ft-lb with fatal results at as little as 900 ft-lb. The actual extent of the fractures and injuries were stated; they consisted of multiple rib fractures with pulmonary and cardiac lacerations.

The rib cage is able to absorb a great deal of impact energy by deformation of individual ribs, by a general downward rotation, and by transmitting loads to the thoracic vertebrae and viscera. Since there is almost always adequate upper-torso restraint found in victims of military-aviation accidents, with consequent distribution of the impact force over a larger area, quite high levels of deceleration are necessary to fracture ribs (in our experience 40 to 60 g). Loose restraints, poor prior positioning, and premature failure of one component of a restraint can adversely redistribute the load and cause fractures in accidents that have lower apparent "total body" decelerations.

CONCLUSIONS AND RECOMMENDATIONS

1. The aviation pathologist can play a role in aircraft-accident investigation that exceeds the activities previously pursued in determining cause of death and identification of the deceased. He may aid the technical personnel of aircraft-accident investigation boards in determining the cause and manner of the accident. This is true even in those cases in which pilot incapacitation and other human-factor considerations have played no part in the cause of the accident.

2. The aviation pathologist must follow a definite PLAN OF ACTION in his activities in order to seek out and organize the great amount of information available and to present it in a helpful and orderly fashion. The following is suggested:

a. Familiarize yourself with the circumstances of the accident.

b. Visit the scene of the accident or the site where the wreckage is being collected.

c. If possible, visit an intact type-model of the aircraft.

d. Perform a careful postmortem examination, paying close attention in particular to x-ray documentation of skeletal injuries.

e. Classify, organize, and analyze injuries.

f. Be careful to recognize the "odd" injury, the case that stands out from the others.

g. Make an initial calculation of impact forces with respect to magnitude, direction, and duration.

h. Formulate a preliminary, medically based hypothesis and find out whether it is congruent with any engineering hypothesis being formulated.

i. Eliminate disagreements between these two hypotheses by mutual refinement until the final formulation of the impact sequence is in accord with both the medical and the engineering data.

3. Each injury should be examined from the standpoint of —

a. The magnitude of the force required to produce it.

b. The duration of the force and whether or not the injury was caused by deceleration, by impact, or by impulse.

c. The area over which the force was applied, particularly with respect to restraints, helmets, and other life-support equipment used.

d. The composition of the impacting surfaces.

e. The direction of the force.

4. Thresholds for injury production have been discussed for abdominal and thoracic viscera, the spine, the extremities, the head, and the thorax. Additional information is needed to determine injury thresholds of the cervical spine (44), upper extremities, and small bones of the hands and feet.

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