NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D.C.

```
- - - - - - - - - - - - - - - - - - -X
In the Matter of:                     :
                                      :
THE INVESTIGATION OF THE USAIR        :
INC., FLIGHT 427,                     :
A BOEING 737-300, N513AU              :  DOCKET NO. SA-510
                                      :
ALIQUIPPA, PENNSYLVANIA,              :
SEPTEMBER 8, 1994                     :
                                      :
- - - - - - - - - - - - - - - - - - -X
```

Pittsburgh Hilton and Towers Hotel
Pittsburgh, Pennsylvania

Tuesday, January 24, 1995

The above-entitled matter came on for hearing pursuant to notice, before JIM HALL, Chairman, at 8:35 a.m., before:

Board of Inquiry

Jim Hall, Member, NTSB
Chairman

William G. Laynor, Deputy Director,
Office of Aviation Safety

Ronald Schleede, Chief,
Major Investigations Division, Hearing Officer

Michael L. Marx, Chief,
Materials Laboratory Division

Office of Research and Engineering

John Clark, Chief, Vehicle Performance Division
Office of Research and Engineering

Technical Panel

Thomas E. Haueter, Investigator-in-Charge,
Hearing Officer

Gregory Phillips, Senior Systems Investigator

Charles Leonard, Operations Investigator

Thomas Jacky, Vehicle Performance Investigator

Cynthia Keegan, Structures Investigator

Roff Sasser, Systems Investigator

Staff:

Michael Benson, Office of Public Affairs

Daniel Campbell, Director
Office of General Counsel

National Transportation Safety Board
National Safety Transportation Board
490 L'Enfant Plaza, SW
Washington, D.C. 20594

Parties to the Hearing

Department of Transportation,
Federal Aviation Administration
Harold Donner
AAI-100
800 Independence Avenue, SW
Washington, D.C. 20591

USAir, Inc.
Captain Gene Sharp
115 Commerce Drive
RIDC Parkridge 2
Pittsburgh, Pennsylvania 15275

Air Line Pilots Association
Captain Herb LeGrow
535 Herndon Parkway
Herndon, Virginia 22070

Boeing Commercial Airplane Group
John Purvis
Jean McGrew
7342 East Marginal Way, South
Building 3-800.3, Bay A2
Seattle, Washington 98108

Monsanto Company
Frank Jakse
800 N. Lindbergh Boulevard
St. Louis, Missouri 63167

Parker Hannifin Corporation
Steve Weik
14300 Alton Parkway
Irvine, California 92718-1814

International Association of
Machinists and Aerospace Workers
Jack Wurzel
73 Auburn Street
Saugus, Massachusetts 01906

C O N T E N T S

I N D E X

I N D E X

P R O C E E D I N G S

[Time noted: 8:35 a.m.]

CHAIRMAN HALL: I call the session back to order.

Before I call the first witness of the day, yesterday during our testimony, we had a witness, one of our investigators, discuss -- I'm sorry. The first witness who was a jump seat rider on Flight 1181, USAir Flight 1181 from Charlotte to Chicago, discussed what was an unusual noise that was reported during that flight.

We would request this morning if there are any other passengers that were on Flight 1181 from Charlotte to Chicago on September 8th, 1994 that have any other information that they think might be beneficial to this investigation, to please contact the National Transportation Safety Board at our offices in Washington, D.C.

They can contact Mr. Tom Haueter or myself, Mr. Jim Hall, if anyone was a passenger on that flight and would have any other information that they thought might be of benefit to this investigation in regard to any unusual noises or information they might have on the flight. This is the flight that preceded the accident flight.

In addition, it was requested by several individuals I spoke to last evening -- and I do not know if we have any more -- do we have any more videos this morning today, Mr. Haueter, that are going to be shown?

MR. HAUETER: Maybe at the end of the day.

CHAIRMAN HALL: If we do have any more video, that we ask the hotel people if they can assist us by dimming the lights so that the videos can be seen as clearly as possible by the individuals in the room.

With that, we will begin by calling our next witness, Mr. David Rusho, a Boeing 737 Flight Control Specialist with the Boeing Commercial Airplane Group in Seattle, Washington.

(Witness testimony continues on the next page.)

MR. DAVID RUSHO, B-737 FLIGHT CONTROL SPECIALIST,
BOEING COMMERCIAL AIRPLANE GROUP,
SEATTLE, WASHINGTON

(Whereupon,

DAVID RUSHO,

was called as a witness by and on behalf of NTSB, and, after having been duly sworn, was examined and testified on his oath as follows:)

CHAIRMAN HALL: Mr. Schleede, if you will proceed.

MR. SCHLEEDE: Mr. Rusho, give us your full name and business address for our record, please?

THE WITNESS: Yes. My name is David Edward Rusho and my business address is the Boeing Commercial Airplane Group in Seattle, Washington, Post Office Box 3707 98124.

MR. SCHLEEDE: And what is your position at Boeing.

THE WITNESS: My position is a lead engineer and post-production engineer, which is, airplanes no longer being produced in the production line at Boeing, so basically the airplane I work on are the 707, the 727 and 737-100 and -200.

In that capacity, I'm lead engineer for flight controls of those airplanes.

MR. SCHLEEDE: Can you give us a brief synopsis of your background and education that qualifies you for your present position?

THE WITNESS: I have a bachelor of science in mechanical engineering from Washington State University in 1958 and a P.E. license in mechanical engineering for the State of Washington in 1976. I have 37 years with Boeing; five years instructional tests working on the 737 and 707. I have 24 years in project design, primarily in flight controls, mechanical design, where I've worked on the 707, 727, 737, 757 and 767.

The past eight years I've been working in post-production engineering.

MR. SCHLEEDE: All right. Are you a designated engineering representative?

THE WITNESS: No, I'm not.

MR. SCHLEEDE: Okay. Thank you.

Ms. Keegan will proceed.

MS. KEEGAN: Good morning, Mr. Rusho.

THE WITNESS: Good morning, Ms. Keegan.

MS. KEEGAN: What was your role in this investigation?

THE WITNESS: I was asked by our Boeing Air Safety Group to participate in this investigation to look at cables. And I was under the direction of Mr. Keegan and the NTSB.

MS. KEEGAN: Why was it important for you to look at the cables? What was the purpose of you looking at the cables?

THE WITNESS: The purpose of the cables, primarily, to see if there's any preexisting cable failures prior to the incident which -- you know, preexisting, if cables had been broken prior to the incident. And also, we hope to gather information to possibly determine positions of the surfaces that these cables control.

MS. KEEGAN: Okay. First of all, could you describe in detail how you went about identifying the different cables and then how you went about locating them and reconstructing them to their proper location?

THE WITNESS: Okay. The cables that I looked at were the aileron bus, the spoiler and the rudder cables. Now, to really understand these cables, we should put the viewfoil up.

MS. KEEGAN: Is that Exhibit 7-J?

THE WITNESS: 7-J, page 7.

MS. KEEGAN: Dave, could you turn toward the microphone when you speak?

THE WITNESS: Yes. Okay. I guess I can't use this pointer.

CHAIRMAN HALL: I believe you can take that microphone over it's holder.

THE WITNESS: Can you see that pointer?

MS. KEEGAN: No. Not from over here.

CHAIRMAN HALL: Mr. Purvis, do you have another pointer?

MR. PURVIS: They're going to get it now.

CHAIRMAN HALL: Okay.

THE WITNESS: First of all, I'd like to say that I participated in this investigation in four phases and those four phases involved going to Pittsburgh to look at these cables. In the first phase, I was told to look at the aileron bus and spoiler cables. Now, if you look at the diagram up there, you can see the aileron bus cables are the ones that are called ABSB and ABSA on the left-hand and on the right-hand. What these cables are, they come from a power control unit located in the wheel well, and they go out on the rear spar to the aileron and they drive the left-hand aileron and the right-hand aileron.

And the reason we call those bus cables is because they basically link the left-hand and right-hand systems together, so they work in concert.

CHAIRMAN HALL: Sir, it would help us if you would just -- if you would on each one of these, although it may be elementary information to some, if you'd tell us where the aileron is located on the airplane and on each one of these where you're going to be describing the cable and what's functioning.

THE WITNESS: Yes, sir. Okay.

The aileron is on the trailing edge of the wing outboard of each wing. There's one aileron in each wing. There's the right-hand aileron and there's the left-hand aileron.

The bus cables come form the power control unit in the wheel wells, and I'll point to it. That says aileron power control units right in the middle of the picture there, right there. That is controlled by the pilot's control wheel through a cable system that goes down the body. The cable system goes through the body to the wheel well.

Okay. Here. I've got something here if I can figure out how to use it.

Okay. Here we go.

So here is the control cables that go back to the wheel well and drive the power control units, which drive the aileron bus cables, which drive the aileron.

The reason we wanted to look at the aileron bus cables is that is an important linkup between the power control units and the ailerons and we wanted to be sure that that linkup had integrity. So the first thing we did was look to see if those aileron bus cables had any preexisting failures.

We located them in the -- they were in the -- this wreckage was in a hangar at the Pittsburgh Airport and we had the wings, the remains of the wings, left-hand and right-hand wings. The rear spar were in place and these aileron bus cables were attached to the quadrants.

So we located these bus cables, identified them, and then after we identified them and measured them in place and looked at the fractured ends to see if there was anything other than tensile overload, we then took them out of the airplane and laid them out and measured the length as exactly as we could. And then we were able to reconstruct it, based on the drawings, the relative position of these cables relative to the airplane.

The spoiler cables similarly come from what we call a spoiler mixer box. Now, there's a difference in these cables. These cables here are 3/16, the bus cables, the largest cables and only large cables in the airplane. The spoiler cables are 3/32.

Now, in this diagram it looks like there's only one cable out here, but this is just for the demonstration. There's actually one spoiler cable for each spoiler. The spoilers are on top of the wing and these are flight spoilers. These only drive the flight spoilers. There's two flight spoilers on the left-hand wing and two flight spoilers on the right-hand wing. And each -- one cable set drives each spoiler.

And from the mixer, each one, the left-hand goes out to the left from the mixers. The right-hand goes out to the right from the mixer also. And this again, comes from an input from the aileron control wheels.

In addition, we have a speed brake input to the mixer, so we can use these as speed brakes in the air. Again, the importance of this spoiler -- finding the spoiler cable is to determine if there was any precondition failure because if they would fail, you would have the spoilers pop up slightly. And part of our exercise here and our investigation was to determine what these cables condition was.

We were able to find a very small amount of the cables attached to the spoilers and they were -- the center portions were all gone. We weren't able to find any of the spoilers.

But on the aileron bus cables, we were able to find practically all of them, even some of the shorter sections in the wheel well.

When I went to Pittsburgh the first time, I took a metallurgist along, a Boeing metallurgist. And what he did, he looked at all of the broken ends of all the cables that we could find in this aileron bus and the spoilers, as well as a whole bunch of cables that were -- of all the cables that were in the hangar. He never found anything other than tensile overload fractures on these cables. And we sent some of these back to the NTSB that we had elsewhere. They also looked at those.

So that was the way we reconstructed the aileron bus and spoiler cables.

Now the rudder cables was a different story.

Oh, I might add that to do this I took a second trip to go back and reconstruct the aileron bus cables. And on the third trip I went back to reconstruct the rudder cables.

Can you put up that other viewfoil there?

(Pause.)

Here's a rudder cable system.

CHAIRMAN HALL: What page number, please?

THE WITNESS: I think it's 6.

MS. KEEGAN: That's correct. That's page 6.

CHAIRMAN HALL: Page 6 in Exhibit 7-J is what we have on the screen now.

Please proceed.

THE WITNESS: Okay. The rudder panels in the cockpit have push rods going back to quadrants, two quadrants, and each of these quadrants have a cable attached to it that go the entire length of the airplane up to the vertical fin to the aft quadrant that drives the PCU. And attached to that aft quadrant is a centering unit.

The length of these cables is 1100 inches and these are 1/8 diameter cables. Back here at the back end we have two turn buckles on each cable. The problem with reconstructing these was that at the hangar, we had a whole series of cables in boxes. What we did, we took all the cables out of the boxes. We separated the cables by diameter. Since we knew we were looking for 1/8 diameter cables, we separated all the 1/8 diameter from the 3/32 diameter cables and in addition, then when we got those, we separated these cables into longer lengths and shorter lengths.

We further separated them to have cables that had turn buckles on them and we could eliminate any cable that had a turn buckle that was not consistent with the rudders. These turn buckles have part numbers on them and we were able to find the four turn buckles that relate to the rudder by finding these part numbers, and then we could eliminate the rest of them.

Then we had a bunch of structures on some of these cables. We further eliminated some of the 1/8 diameter cables that had structures on them, and in doing so we were able to find three cable that ran through the body that were associated with the rudder.

We had two cables, called the RA on this side, and we found one called the RB on this side.

CHAIRMAN HALL: Dave, could I ask you just a couple of very simple questions? Could you show us exactly where the peddles are that the pilot and co-pilot would push on that drawing?

THE WITNESS: Here are the -- the pilot's peddle is right here and here are the co-pilot's peddles.

CHAIRMAN HALL: Okay. And when the cable runs back through the length of the plane, is it running through the floor of the plane? What is it actually running through?

THE WITNESS: This cable runs on the right side of the centerline of the airplane, 4.5 inches to the right. This one runs 4.5 inches to the left. They go through the pressure bulkhead and as soon as they go through the pressure bulkhead they go up to the vertical fin.

CHAIRMAN HALL: Thank you.

THE WITNESS: An additional thing we looked for was structure. We found an upper pulley on the RB system that had a -- the cable was pinched on to that, so we were able to identify that one. And then we were able to identify two little sections that attached and were broken off the aft quadrant and were able to match those with the aft quadrant. So we were able to get quite a bit of structure of cables back in here and get a pretty reasonable idea of I think what that cable situation was.

So that's basically how we reconstructed these.

MS. KEEGAN: Okay.

THE WITNESS: I might add that a metallurgist looked at all these cables with a 10x magnifying scope, the fractured ends.

MS. KEEGAN: Describe the purpose of looking at the cables with a magnifying glass?

THE WITNESS: What we were trying to do is we were trying to find out if these fractured ends were due to fatigue, due to tensile overload, due to wear or due to corrosion.

MS. KEEGAN: Your viewgraph, page 5 of this exhibit, I'd like you to get into some detail about what you examined and what your findings were as far as when you located the cables and how exactly you located the cables and at what station locations you located them.

THE WITNESS: Okay. This is a reconstruction of our rudder cables based on measured lengths. Oh, yes. We measured all the length of these cables. Tried to measure them as accurately as we could in the hangar area.

What this is is a reconstruction, a calculation of a reconstruction of these cables. This section here is based on the rudder being at a neutral position.

CHAIRMAN HALL: Dave, again, are we looking at the airplane? Could you give us a feel of how this is laid out?

THE WITNESS: Okay. This is the aft quadrant up in the vertical fin at the back end of the airplane and the pressure bulkhead -- see where it says here aft pressure bulkhead? So that's the back end of the airplane.

These straight sections, straight cables, go right through the body, all the way to the front of the airplane.

CHAIRMAN HALL: So we're not looking at the whole airplane. We're just looking at the -

THE WITNESS: No. We're looking -- well, we are looking at kind of a shortened version of the airplane, but this only shows the cables that we got, that we were able to find.

So if you look at the reconstruction of these based on this, these two ends here did not match.

MS. KEEGAN: Dave, could I just stop you for just a second here?

THE WITNESS: Yes.

MS. KEEGAN: Station 420, I see it, the forward end. Whereabouts on the aircraft is station 420?

THE WITNESS: Well, that's in front of the wing towards the front of the airplane. This station here is aft of the wing towards the back of the airplane. This is right over the wing box area here.

So we don't really have any cables up front other than this small section here. This is the furthest one we had up front.

MS. KEEGAN: When you say we didn't really have them, are you saying that you didn't find them or that it was difficult to identify their proper location? Would you be a little more exact with that?

THE WITNESS: We couldn't really identify them. All those 1/8 diameter cables look alike and they're broken up into various lengths. The only way we could identify them is locating them through structure.

These were free in structure here. This one was pinched here but we were able to -- that's was the only way we could identify them.

MS. KEEGAN: Now when you say it's pinched, do you -- how did you come to the conclusion that it was pinched and how could you determine whether it was a result of the impact from the crash or that -- whether it had become pinched prior to the impact?

THE WITNESS: Well, it's consistent with the destruction of the airplane and it was -- the idler, the bracket holding the idler was just crushed into the rub, and the rub was all broken up.

MS. KEEGAN: Dave, what do you mean by pinched?

THE WITNESS: Pinched means that it was hard to move. You couldn't pull it through there.

MS. KEEGAN: And as far as locating the cable at this pinched idler pulley at Station 767, how far back then were you able to locate the cable and how did you know that the cable in fact went in the direction aft instead of forward?

THE WITNESS: Well, we know that the idler pulley is on the rear side of the floor beam and then we're able -- then measuring this, we're able to determine what the aft most position of the broken end of this cable was. When we found that out, we found that there's a 21 inch overlap between this cable that comes from the aft quadrant to the horizontal floor beam cable. But we confirmed that these two cables matched, so we were convinced that this was a match.

MS. KEEGAN: How do you account for the overlap?

THE WITNESS: Well, we think what happens is this cable is under tension during the accident and what happened, it broke and then pulled back and then pinched at this point.

One of the pieces of evidence that we have is at station 767-C, which is 20 inches forward of this station here, there is a -- going through the hole on RA, there was a notch the same diameter as the cable. We think at that point is where the cable broke bending over that hole and then it broke at that point and then pulled aft about approximately 20 inches and then ended up in this position with the collapse of all the structure here.

MS. KEEGAN: Dave, I'd just like to make sure. Are we talking about the right or the left cable?

THE WITNESS: This cable drives the -- it's the right -- it's on the right-hand side on the bottom but it drive the rudder left.

MS. KEEGAN: Okay. You mentioned a notch. Could you please describe what your examination of a notch revealed and how you came to a conclusion of whether it was a pre-impact type of a condition or post-impact?

THE WITNESS: Whether the notch was pre-impact? Well, I don't know if I can really do that. All I can say is this consisted of the failure mode I described.

MS. KEEGAN: Could you give me a little more detail about the failure mode you described just once more?

THE WITNESS: Well, the failure mode would be that if the cable broke at station 727-C, that's where the notch was. That's where the cable is bent around the hole. And because of that high loads, it broke at that point and then pulled back. And that would be -- if it was at 727-C, that would be 6 degrees right rudder.

MS. KEEGAN: The cable that runs all the way -- your right cable then that runs all the way to the rudder PCU, can you just go through and describe your findings aft of the galley area and what you found as far as any indications that you found that the cable had integrity prior to impact?

THE WITNESS: Well, yes. The evidence points towards the cable having integrity or not having any preexisting failure, primarily because there was multiple fractures at the back end, in the back pressure bulkhead. There was also noticeable fractures along the body cable run and we didn't find anything other than tensile overloads on any of the cables. So the evidence strongly points towards that the cable was intact at the time of the incident.

MS. KEEGAN: Could you please five your

opinion as far as the examination of other control, flight control areas such as pulleys, fair leads? What did you examine and what were your findings?

THE WITNESS: Well, we didn't really specifically just go out and look at pulleys and fair leads. We did have a pulley in the upper overhead on the RB that had a pinched cable also. There was -- and also, there was some -- the eyeball seals at the pressure bulkhead, they had some indications of notching on them.

MS. KEEGAN: You're -- I want to just make it clear on how you identified the spoiler, aileron and rudder cables individually and how you separated those cables. Could you just go over that one more time?

THE WITNESS: The elevator cables?

MS. KEEGAN: The spoiler -- yes -- rudder and the aileron cables. Could you describe how you separated those and what you found in the hangar as far as the condition of all the cables and the difficulty or the --

THE WITNESS: Yeah. Okay. The spoiler cables were -- the only spoiler cables we found were intact on the rear spar attached to the quadrants at the actuator locations, and they were -- we had one long cable and the rest of them were like 4 or 5 feet long.

We identified them by the positioning, their positions on the quadrant. We were able to identify which cable by their position on the quadrant.

The aileron bus cables, since they're the 3/16 diameter, they were much easier to identify and it was on the -- as far as the rudder cable, the identification was only by the attachment of floor beam structure.

MS. KEEGAN: What was your goal in relocating the cables through the floor beams and relocating them to their proper location? What were you trying to find out from locating these cables?

THE WITNESS: Well, there were several things that we hoped to accomplish by doing this. One of them was, of course, to determine if there was any precondition or preexisting failure of the cable. The other thing was to be able to locate the fracture surfaces with structure and try to identify the position of the cable so we could try to establish what the rudder position was in.

Another possibility that we thought -- looked early onto was there's an auxiliary fuel tank just after the -- in the aft body area, and we wanted to see if there was a possibility that that could have had some kind of impact on the floor beams and possibly displace the rudder cables.

MS. KEEGAN: And what were your findings?

THE WITNESS: We found no indication on the auxiliary fuel tank that it had any displacement. And the tank itself was looked at and they found no problem with that.

MS. KEEGAN: What is the history of in-flight failure binding or any type of problem with the rudder cables on the Boeing 737?

THE WITNESS: On the Boeing 737 we have no history of in-flight problems of the cable system.

MS. KEEGAN: And the same question for the aileron cables. Do you have any history of in-flight cable of the aileron cables on the Boeing 737?

THE WITNESS: Yes. We've had some failures on the aileron. We had three failures that I know of on the aileron body cables and five on the aileron bus cables.

MS. KEEGAN: And what were the circumstances surrounding those failures?

THE WITNESS: I don't know what the circumstance on all of them were, but we did have an aileron bus cable that was worn out and basically failed after a high number of hours. It failed on takeoff.

I believe we had another one that was also a similar in-flight failure.

MS. KEEGAN: Did you exhibit any evidence of the same type of problems on this on USAir Flight 427 wreckage cables?

THE WITNESS: WE looked hard for evidence of any wear on these cables and they are pretty easy to determine if you've got wear. You get wire breakage around the pulleys and we found nothing that had anything like that at all.

MS. KEEGAN: And did you see anything unusual with your examination of the spoiler cables in the wreckage?

THE WITNESS: The spoiler cables were all tensile overload failures and we didn't see anything that was unusual.

MS. KEEGAN: And what is the history of spoiler cable problems with the Boeing 737?

THE WITNESS: To my knowledge, we've had 13 failures of the spoiler cables.

MS. KEEGAN: And what were the problems with those failures? What was the cause of those failures?

THE WITNESS: They were corrosion and wear. Usually corrosion on those cables.

MS. KEEGAN: Did you find any evidence of corrosion or wear on the spoiler cables in the USAir wreckage?

THE WITNESS: We didn't see any corrosion on I don't think any of the cables. The cables were all in very good shape.

MS. KEEGAN: Okay. Thank you very much, Mr. Rusho. That concludes my questions at that time.

CHAIRMAN HALL: Any of the parties desire to question the witness?

Boeing. Anyone else?

(No response.)

If not, who's doing the questioning?

Mr. McGrew?

Please proceed.

MR. McGREW: Thank you, Mr. Chairman.

Mr. Rusho, with respect to the RA cable which you found pinched, in the unlikely circumstances that that was pinched in flight, what would be the effect on the operation of the rudder?

THE WITNESS: In that case you would control it with the ailerons.

MR. McGREW: But would the rudder move?

THE WITNESS: No.

MR. McGREW: Would it move to the right? If that cable were pinched, could the rudder move to the right?

THE WITNESS: No.

MR. McGREW: So the rudder would be locked in position?

THE WITNESS: It would be locked in position.

MR. McGREW: Thank you.

In conclusion, then, did you say that your investigation showed that all of the rudder cables were intact prior to the impact? Is that your conclusion?

THE WITNESS: Yes. That's our conclusion.

MR. McGREW: And so you found --

THE WITNESS: This is our -- our structural people agreed on this also. It was the conclusion of the group.

MR. McGREW: So you found no evidence of any preexisting failures in the rudder cable system?

THE WITNESS: No. No evidence at all.

MR. McGREW: Okay. Thank you very much.

CHAIRMAN HALL: All right. No other questions from the parties? We will proceed with Mr. Marx.

MR. MARX: I just had a few clarifying questions.

You mentioned that a metallurgist from Boeing was on scene or at the hangar looking at the cables and that he used a 10x power, a hand lens, to take a look at these fractures. Would you clarify -- I understand quite a few of these cable sections were sent to the

Materials Lab in Washington. Which other examinations were done? Do you recall how many of these cables and why you sent them to Washington?

CHAIRMAN HALL: That's our laboratory, right, Mr. Marx, that you're referring to?

MR. MARX: Yes. That's correct. That's correct.

THE WITNESS: Pardon me? What was that?

MR. MARX: Well, I just want to know for what reason they were sent to Washington?

THE WITNESS: We sent, I think, four of them. Meanwhile, -- these were the more -- the typical cables were a little more controversial and our metallurgist wanted confirmation that his reporting was correct.

MR. MARX: Okay. And the Materials Lab in Washington examined these at much higher magnifications than a 10x?

THE WITNESS: I believe so.

MR. MARX: Okay. Thank you.

CHAIRMAN HALL: Mr. Clark?

MR. CLARK: Mr. Rusho, would you describe what you would expect to happen if a rudder cable did break?

THE WITNESS: If a rudder cable broke, you would get a displacement of the peddles and you would have the centering unit be the focal point of the rudder and you could control the airplane with the rudder trim.

MR. CLARK: Would you also be able to control the rudder in one direction with the one peddle?

THE WITNESS: Yes. You could -- you'd have one cable that could still be put in tension and you could position the rudder with that one cable.

MR. CLARK: I believe you referred to some litmus marks on the cable that if they did occur at the impact, at the crash, that they were in a position to command a 6 degree airplane move with the right rudder?

THE WITNESS: Yes. That's based on that notch at station 727-C bulkhead.

MR. CLARK: Were you involved in the examination of the pogo?

THE WITNESS: No, I wasn't.

MR. CLARK: Over the course of your work, have you attempted to -- or have identified or attempted to identify any mechanism in which a band could produce a slow moving rudder?

THE WITNESS: No, I haven't.

MR. CLARK: Are you aware of anybody at Boeing that has attempted to do so?

THE WITNESS: No. I don't know anybody that has.

MR. CLARK: I have no further questions.

CHAIRMAN HALL: Mr. Schleede?

MR. SCHLEEDE: Thank you.

When Ms. Keegan asked you about the different in-flight failures, I believe you said no history of in-flight failures of rudder cables?

THE WITNESS: Correct.

MR. SCHLEEDE: Is there any other history in the 737? Are you're aware of any other kind of jams caused by a falling object or interference or ice or any other mechanical interferences that cause rudder cable jams?

THE WITNESS: Well, I don't know. I'm not aware of any. We haven't researched that.

MR. SCHLEEDE: Are the slats your area of responsibility as far as flight controls?

THE WITNESS: No.

MR. SCHLEEDE: I want to have the staff assist and bring up Exhibit 11-A-1. She'll place it right on top to your left there. I believe we have another witness to cover this, but I thought I'd ask you before you leave.

This is the maintenance record, Group Chairman's Report, Addendum 1, and it's reference maintenance history of rudder PCU change on the accident airplane January 21st, 1993.

I'm particularly interested in the second and third paragraphs. In the second paragraph it mentions that there's a work card generated on the main rudder PCU, output rod with chaffing damage. So the damage was cleaned up and inspected probably within minutes.

The next paragraph talks about another work card describing the replacement of a damaged main bolt.

Before I ask a question, is this an area -- are these the type of things within your area of responsibility as a Flight Control Specialist?

THE WITNESS: Well, it would be, but in this accident I was only involved in the cables. My area of responsibility is strictly the cables.

MR. SCHLEEDE: They're your normal responsibilities in your job?

THE WITNESS: Well, possibly -- yes, it could be that it applied to the 737-100 and 200 or the 300. This was probably addressed by someone --

MR. SCHLEEDE: So you wouldn't be able to answer any questions about --

THE WITNESS: No. I'm not familiar with this.

MR. SCHLEEDE: I'm sorry. I didn't hear?

THE WITNESS: I'm not familiar with the whole thing so I couldn't answer your questions.

MR. SCHLEEDE: Thank you.

CHAIRMAN HALL: Mr. Laynor?

(Pause.)

Well, we are in a temporary recess while the Court Reporter restores her line feed.

(Whereupon, a recess was taken.)

CHAIRMAN HALL: This hearing is back in session. The Court Reporter is ready to go. Is that correct? And we will proceed then with questioning by Mr. Laynor.

MR. LAYNOR: Mr. Rusho, I'd like to refer you, again, to Exhibit 7-J, page 6.

And Jerome, if you could put that up.

In your testimony apparently some confusion still exists regarding the 21 inch overlap at station 1049.5 in the lower right-hand corner of that exhibit.

Can you explain the significance of that again, please?

THE WITNESS: Well, we think that it was broken at station 727-C, where the notch was, and then after it broke, the tension in the cable collapsed all at once and it pulled back 20 inches and was pinched at the station 727 by the idler pulley. And that counts for the calculated differences in the length.

MR. LAYNOR: So, the -- let me see if I can get it straight. In your opinion, the notch would represent impact damage that would be consistent with the rudder position at the time of impact and the overload -- and the overlap -- I'm sorry -- represents cable stretched due to tension?

THE WITNESS: No. It represents displacement of the cable 20 inches. The cable moved back to station 727-D was where we found it in reference to station 767. There's a 20 inch difference between the floor beams. So 60 inches forward at 767 is where the cable was broke. But we think what it did is it actually moved -- it was actually 80 inches forward at the time of the fracture and then pulled back to the position we found it in. And that accounts for the 20 inch overlap.

MR. LAYNOR: And if I go with the 80 inches forward at station 767, what kind of rudder position would that correspond to?

THE WITNESS: That would be 6 degrees right.

MR. LAYNOR: What kind of rudder position would the 60 inches forward correspond to?

THE WITNESS: You only have 4-1/3 inches to travel to get full throttle, so it wouldn't be applicable to any position at all.

MR. LAYNOR: All right. And you may have answered this already, but I wasn't sure. Were you involved in the examination of the centering spring mechanism and the trim actuator?

THE WITNESS: No, I wasn't. All I did was the cables.

MR. LAYNOR: Okay. Thank you, sir. That's all I have.

CHAIRMAN HALL: Just a few brief questions. But first, I would appreciate if we could put up that diagram of the plane. And I don't know what exhibit that is.

Cindy, do you know or Tom know off hand?

There we go.

If you could identify for us -- I believe you talked about the spoilers, the ailerons and the rudders being driven by cables; correct?

THE WITNESS: Yes.

CHAIRMAN HALL: Now that we've got the full airplane, if you could show me where those pieces are, and I would appreciate it.

This is Exhibit 9-S, page 1.

THE WITNESS: The ailerons are these segments on the trailing edge right here. The spoilers are -- the flight spoilers are these two on opposite sides.

Yes. These two right here, these are -- the two outboard ones are ground spoilers and another inboard one is a ground spoiler.

So if you look at the two spoilers that we're looking at on the left-hand wing are flight spoilers and here is the aileron.

CHAIRMAN HALL: Now, what activates the cables in a situation of each one of those? Begin with the rudder, if you would. In the cockpit or --

THE WITNESS: Okay. The rudder is activated by the pilot's peddles and/or the co-pilot's peddles and he drives the cable system back to the PCU in the fin, vertical fin. The ailerons are driven by the control wheel bringing cables back to the power control unit in the wheel well. That wheel well, the power control unit then drives the aileron bus cable. That is the output of the power control unit.

The output of the spoilers are driven basically through the aileron control wheel. It then goes through the meter box and the cable drives actuators at the spoiler, at the flight spoiler positions.

CHAIRMAN HALL: How many feet of cable are we talking about?

THE WITNESS: There's 1100 inches of cable for the rudder; approximately 422 inches of each aileron bus; and approximately 260 inches for the spoiler cables, left spoiler and right spoiler.

CHAIRMAN HALL: So you have a lot of cable to sort through in the hangar.

THE WITNESS: Yes, we did.

CHAIRMAN HALL: Now is that color coded? How do you tell the spoiler cables from rudder cable? Has it got different colors on it? Does it not look alike? Is it different size? How would you tell the difference?

THE WITNESS: The cables are separated by 1/8 diameter cables. The aileron, through the body, the elevator, the stabilizer trim, the flap controls, speed brake, are all 1/8 diameter cables. The aileron bus are 3/16 diameter cables. The spoiler cables are 3/32, as well as the brakes cables and the engine control cables.

So, when you have a whole bunch of broken up cable like that, it's very difficult to determine what they are. In fact, that's a big problem. We couldn't really determine all the cables. We had to rely primarily on the structure that it was attached to or the part numbers on the turn buckles. And some of the part numbers on the turn buckles were burnished off.

CHAIRMAN HALL: Now how many individuals assisted you in this task of trying to identify the cables?

THE WITNESS: Probably throughout the stage it's probably about a half a dozen people.

CHAIRMAN HALL: Now, you mentioned that your responsibilities at Boeing primarily covers the older aircraft that are not presently in production?

THE WITNESS: That's correct.

CHAIRMAN HALL: And I believe you said that there can be cable failures from fatigue, tensile overload, wear or corrosion?

THE WITNESS: Right.

CHAIRMAN HALL: What is the lifespan of a cable?

THE WITNESS: Well, I don't think there's any rule of thumb on the lifespan other than it depends a lot on the maintenance of the cables. And we recommend you replace them when you get to a certain wear condition, which we have defined in the maintenance manuals.

CHAIRMAN HALL: And the maintenance manuals are basically approved by the -- under federal regulation for that airplane or is that just a manufacturer's --

THE WITNESS: That's Boeing's recommendation for the maintenance manual.

CHAIRMAN HALL: So there's not a specific lifespan, but generally as an aircraft gets older that there is a possibility that those cables may be replaced as they become worn through fatigue, wear or corrosion?

THE WITNESS: Yes. But I might point out that fatigue is really not problem in our design. Where we get into fatigue problem is due to misrouting of the cables over keeper pins on the pulleys. That's the only place I've ever seen fatigue on a cable.

CHAIRMAN HALL: Okay.

THE WITNESS: So, -- but we look for that. That's one we looked for just to be sure.

CHAIRMAN HALL: All right. Well, I appreciate the time that you and your colleagues have spent in going through the cables and reconstructing them to the best of the ability with -- given the condition of the wreckage and appreciate your testimony this morning.

You're excused, sir.

THE WITNESS: Thank you.

(Witness excused.)

CHAIRMAN HALL: The next witness is Mr. Lester Berven. I hope that is the correct pronunciation. If not, I will ask him to provide that.

He is a flight test pilot with the Federal Aviation Administration in Seattle, Washington.

(Witness testimony continues on the next page.)

LESTER BERVEN, FLIGHT TEST PILOT, FEDERAL AVIATION
ADMINISTRATION, SEATTLE, WASHINGTON

(Whereupon,
LESTER BERVEN,
was called as a witness by and on behalf of NTSB and, after having been duly sworn, was examined and testified on his oath as follows:)

CHAIRMAN HALL: Mr. Schleede, if you would proceed.

MR. SCHLEEDE: Yes.

Mr. Berven, would you state your full name and business address for our record?

THE WITNESS: My name is Lester Berven. I work in the Renton Office --

MR. SCHLEEDE: Get closer.

THE WITNESS: Is it on?

CHAIRMAN HALL: Is the witness' microphone working?

MR. SCHLEEDE: Try it again.

THE WITNESS: There we go.

MR. SCHLEEDE: Seems to be now.

CHAIRMAN HALL: Just have to speak closely into it, please, sir.

THE WITNESS: My name is Lester Berven. I work as the -- in the FAA Office in Renton, 1601 South Lind Avenue.

MR. SCHLEEDE: What is your position with the FAA?

THE WITNESS: I'm the senior flight test pilot for the FAA's Northwest Mountain Region, which includes the Boeing Company.

MR. SCHLEEDE: How long have you worked for the FAA?

THE WITNESS: Worked for the FAA since 1976.

MR. SCHLEEDE: Give us a brief description of your education and background how that qualifies you for your present position?

THE WITNESS: Certainly. I have a bachelor of science degree in aeronautical engineering with some post-graduate studies in aerodynamics and aircraft systems safety. I have an airline transport pilot rating. I'm rated in -- I have type rating in all the Boeing airplanes except for the 707.

I worked for eight years at Edwards Air Force Base in Flight Test and five years in industry as a test pilot and I've worked for the FAA since 1976 as a certification test pilot.

MR. SCHLEEDE: You do have type rating in the 737?

THE WITNESS: Yes, I do.

MR. SCHLEEDE: And approximately how much flight time do you have in total time and time in the 737?

THE WITNESS: My total flight time is somewhat over 7,000 hours and I believe I have about 400-500 hours of flight test experience in the 737 series.

MR. SCHLEEDE: Thank you.

Mr. Jacky will proceed.

MR. JACKY: Thank you.

Good morning, Mr. Berven.

THE WITNESS: Good morning.

MR. JACKY: Could you briefly describe the responsibilities of an FAA flight test pilot?

THE WITNESS: Certainly. When an applicant such as Boeing builds a new airplane and takes it out in flight test themselves and develops it to the point where they think it's a good machine, they submit it basically to the FAA. And as part of that process, we go out and determine compliance with airworthiness rules of Part 25.

It consists of performance and flying qualities and systems evaluations.

MR. JACKY: Could you describe what is Part 25, please?

THE WITNESS: Part 25 is part of the Code of Federal Regulations which specify the airworthiness standards for transport airplanes.

MR. JACKY: And could you describe your experience in FAA certification flight tests, please?

THE WITNESS: Well, our office basically covers all types of different airplanes. I've worked in the transport airplane field in both the small business jet transports and all the way up through the large airplanes, also.

I've participated in essentially all of the Boeing certification flight testing since about 1978, and so that would consist of 727 modifications and approvals and 737, 757-67, the 474-400 and currently the triple 7.

We do modification testing on other business jets like Lear Jets and Falcon Jets and small aircraft, also.

MR. JACKY: And with the 737 aircraft, were you involved in the certification of the 300 series?

THE WITNESS: I was. Yes.

MR. JACKY: And any of the other of the series of the 37?

THE WITNESS: I've also done some testing on the 737-200. I wasn't working at the FAA in Seattle at the time of its original certification, but some of the follow on modifications for autopilot testing and some engine modifications and also some after-market stuff for a noise suppression on an applicant other than Boeing.

MR. JACKY: As part of the FAA's certification of an aircraft, can you describe what sort of flight tests would be accomplished on that airplane?

THE WITNESS: Certainly. Once the aircraft is developed to the point where it's structurally safe and the ground structures tests and flutter tests and Boeing has basically conducted a minimum set of airworthiness performance and flying qualities test so that the aircraft is basically safe for flight testing, the FAA issues --

CHAIRMAN HALL: A flutter test? What is a flutter test?

THE WITNESS: Oh, an aircraft is not a fixed solid body but it is flexible. And as you take the airplane to higher and higher speeds at certain weights you can get into modes where the aircraft starts to vibrate uncontrollably and that's called flutter. And so what we want to make sure is that the airplane doesn't do that, and so that's what the flutter testing is. They do ground testing to find out what the local resonances for all the flight control systems and interactions are, then they do it in flight testing, also.

CHAIRMAN HALL: Thank you.

THE WITNESS: Okay.

We were talking about the process of flight testing in a transport airplane. When the primary safety tests have been completed and our structures and systems and propulsion people and the FAA aircraft certification office are happy that the airplane is ready for flight testing, they issue what we call a type inspection authorization, which is kind of an authorization for my group to go out and fly a transport airplane and check its compliance with the airworthiness rules.

And once that's issued, basically we work together closely with the Boeing Company and we have a very detailed test plan which shows when it's going to be done, how it's going to be done and how many points are going to be done. And we go out and we do all these tests, which consist of takeoff and landing performance and minimum engine out control speed and stability and control and all different altitudes, and stalls and stall characteristics, and also proof that the systems and the avionics in the aircraft all perform their intended function.

MR. JACKY: And as part of this

certification, do you perform any flight tests with regard to the control surfaces of the airplane?

THE WITNESS: With regard to control surfaces? Are you talking about augmented, like an aileron -- I mean, an autopilot testing?

MR. JACKY: Yes, but specifically at this point in regards to the primary controls, such as aileron, elevator, rudder controls.

THE WITNESS: We test those from the standpoint that we do stability control testing. That is, we take the aircraft to its -- all it's approved -- it's maximum approved altitude and actually beyond its maximum approved speeds to show that we have some margins in the airplane. And for the lateral directional case, for instance, that is the rudder and the aileron, we do what we call steady heading slide slopes where we stabilize at various speeds and then put in -- opposing the rudder and aileron to maintain the heading and track of the airplane and go all the way to full deflection to see that the forces and moments on the control system are linear and don't reverse so it moves in a stable direction.

So in that case, we do do a control system evaluations.

CHAIRMAN HALL: Excuse me, Mr. Jacky, just a moment. Could you help us just by explaining a slide slope for us?

THE WITNESS: Certainly. Basically, the optimum way to fly an airplane is to point it directly into the wind because it has the minimum profile drag area when you look at it from the front. If you don't do that, you pick up drag and also in some cases where you get the excessive slide slip, some buffeting.

So the purpose of the stability, directional stability of the airplane, is to keep the airplane pointed straight ahead into the wind.

The pilot can change that and he normally has to do that on a slide slip or for some type of maneuvering. If he'd just push on the rudder and then use opposite ailerons so that the airplane doesn't roll and basically can set the airplane sideways to the wind so that you're flying sideways like this.

And so, for instance, instead of the airflow going directly into the front of the nose of the airplane, it's coming in like a side window. That's a side slip.

CHAIRMAN HALL: Thank you.

MR. JACKY: And as part of the certification flight test, do you ever perform or look at control surface hardovers or going to the full deflection at all?

THE WITNESS: Not in the primary flight control system, no. The presumption -- well, the airplane is designed to have enough control power to basically do whatever the pilot wants any time he wants to do it. So, you have enough control power in the elevators and the ailerons and in some cases in the rudder to make the airplane do some rather unusual maneuvers.

So, the presumption is that the flight control system is basically, from the standpoint of full deflections, it's just as safe as the primary structure. So we don't presume and we don't test any types of full deflection hardovers of any of the flight control systems.

MR. JACKY: Okay. Thank you.

Could you explain your role or your participation in this accident investigation?

THE WITNESS: I've only been formally on a couple of accident investigations. One was on a Lear Jet and I was just kind of attached to one of the overrun accidents there at LaGuardia. I can't remember the name of it. And I just kind of acted as a consultant. I haven't done a lot of formal accident investigation.

MR. JACKY: In terms of the accident of USAir 427, what was your participation?

THE WITNESS: I basically acted as a pilot consultant to the performance group and I flew a couple of the simulator sessions: one, to look at controllability; and also to look at the vortex interaction.

MR. JACKY: And would that be under the Aircraft Performance Group?

THE WITNESS: Yes.

MR. JACKY: Prior to the simulator -- or, let me ask you this.

Where were the tests performed that you

participated in?

THE WITNESS: The tests were performed in the en-cab there at Boeing Company.

MR. JACKY: Is this the simulator that Mr. Kerrigan spoke to yesterday?

THE WITNESS: Yes, it is.

MR. JACKY: Prior to that, did you have the opportunity or did the FAA have the opportunity to do any simulator testing with Boeing?

THE WITNESS: Yes. We sort of did some on our own initially right after the accident.

MR. JACKY: Could you characterize the events leading up to that session?

THE WITNESS: Certainly. After the accident occurred, we were quite aghast that this thing could possibly happen because we've tested this airplane to all kinds of strange and unusual maneuvers and well beyond the limits of the air speed and stall characteristics and autopilot and yaw damper hardovers and found that there was really nothing wrong at all with the airplane at all.

So, we were taking quite aback -- taken aback that something like this could happen. So one of our pilots in discussing what the heck could possibly cause this sort of thing, had a chance to fly on a 737 simulator for another test. Basically it was the development of a head-up display system. And during that test, while he was in the en-cab simulator, it turned out that the head-up display didn't work very good and he had to sit there for 40 minutes for them to fix it.

So, while he was there, he decided to play around with flying qualities of the airplane and he did some checks for rudder/aileron trades. That is, statically. We're talking about straight ahead steady heading slide slips. And discovered that -- pretty much what Mr. Kerrigan said yesterday -- that at the accident condition of flaps 1 and 190, that if you put the aileron and rudder in very slowly, you're basically balanced right there.

Full rudder and full wheel will just maintain control of the airplane. If you go faster than that, the ailerons have more control power and if you go slower than that, the rudder has more control power.

But that's a normal characteristic and it's certainly acceptable, and a lot of airplanes are like that, too.

He then decided to try some dynamic inputs for the rudder to see if that could possibly be the problem. So, stabilized at 190 and flaps 1, basically with the autopilot turned on and stabilized in level flight, he just basically pushed on the rudder all the way to the stop. Took about 2-1/2 to 3 seconds to get there. And he was quite surprised at the response of the airplane. It rolled quite rapidly into the rudder deflection. And as quick as he could react and disconnect the autopilot, he was up to about 50 to 55 degrees.

And as he added back pressure to hold the nose up and then fed in some left aileron to try to stop the roll -- the airplane essentially rolled all the way over to about 120 to 140 degrees. He didn't continue the maneuver because he didn't want to crash the simulator and mess up the head-up display test, but he thought it was quite interesting and he did it a couple of times.

And so he recovered from the maneuver and then reported back to us that this might be an interesting area to look into to see if this could be a possible cause of the accident. So, we called the Boeing Company and said, "As part of our continued operational safety responsibility, we'd like to take a look at the flying qualities and controllability of this airplane and the dynamic rudder input, which we hadn't done during the certification tests."

And they set up a four-hour session for us and we wrote up a little test plan and basically went into the simulator and did essentially what the performance group mentioned a little later on. I might add, with just the same results, too.

So we looked at several different things: trim runaways and different rate, hardovers on the rudder and the aileron rudder trades and stalls and several other things.

MR. JACKY: Previously when you were discussing the tradeoffs between the rudder and the ailerons, you said that that was a normal characteristic of the airplane. Is that correct?

THE WITNESS: That's correct.

MR. JACKY: Could you describe why that is a normal characteristic, please?

THE WITNESS: Well, basically, what we're looking for is in our airworthiness rules we want the airplane to fly normally. That is, when a pilot gets in a new airplane he wants to be able to transition and use his previous experience. So there are some characteristics that make up what a normal airplane feels like, and one is the ability to roll the airplane with the rudder, and the other one is that when you do side slip the airplane intentionally, it requires opposite ailerons to stabilize. That's basically an airplane characteristic since day one, so we want them to fly like that so it feels normal.

Now, how much aileron you use for a given rudder is really a function of the different airplane design and the size of the vertical fin and the length of the fuselage and such like that. So basically, we go out and define what that is and so we stabilize at particular speeds and particular flaps headings and we do these side slip tests and we make a plot of the aileron versus rudder deflection to look to see that it's not too steep, it's steep enough, and it doesn't become non-linear at the end. And basically, that's a test that you do for all airplanes.

That basically defines the lateral directional stability of the airplane.

MR. JACKY: And it's your belief that all transport category aircraft behave in this manner?

THE WITNESS: Yes. All transport category airplanes roll due to rudder and in the correct direction.

MR. JACKY: If I could refer your attention to Exhibit 13-B, page number 4, what this is is a listing of simulator failures or malfunction scenarios attempted by the Aircraft Performance Group in the Boeing en-cab simulator.

Were you present at the time that these tests were performed?

THE WITNESS: Yes, I was. I flew about half of them, by the way.

MR. JACKY: Okay. What I would like to do is work my way down this list and ask you about what basically each test is and how it's performed and what were the results.

For example, Number 1. Could you please explain the one engine cut at climb power, please?

THE WITNESS: Yes. Basically, what we're looking there is that when you lose an engine on an airplane, a couple of different things happen.

Number one, you lose the thrust of that engine and you also build up a drag because now you're blowing the engine around by the air like a pinwheel. So you both lose thrust and increase the drag on that side, which is essentially the same as putting rudder in in that direction, and so you wind up in the same kind of a side slip situation we talked about before. So that if you cut the left engine, the nose goes left and you're side slipping to the right, which makes the airplane roll to the left.

And so we were looking at the characteristics of how much will it roll when you cut the engine at climb power. Is it a very rapid departure or can you control it easily.

So basically, what we did, we set the airplane up at 190 knots at climb power, which is maximum continuous thrust, actually, at 190 knots and flaps 1 and just shut the fuel off on the left engine. And then we looked at the resulting reactions of the airplane. And basically, it was not a significant problem. If you don't put any control input at all, the airplane only rolls about 11 degrees per second. It completely controls free with no pilot input at all.

If you use a representative delay, which is what we use for autopilot testing, which is pilot reaction plus 3 seconds, in other words, the pilot knows something happens. It gets it attention and then we wait 3 seconds to give him time to react. The airplane basically will roll only to 45 degrees in that scenario with no pilot input. So it was rather a benign maneuver.

MR. JACKY: In Number 2, we have several rudder hardover rates, A through F. Could you please describe what the practical application of each of these rates would be? What type of rate or why would you expect those types of rates in the airplane or what could be the cause of those type of rates?

THE WITNESS: Well, the first rate --

CHAIRMAN HALL: Again, just before we get into this, Mr. Jacky, if any one of you all could give me -- when you say rudder hardover, what's hardover? What are you referring to?

THE WITNESS: That comes from an autopilot testing term. And basically, if you're letting a black box fly the airplane, you want to be assured that whatever it can do in its worst case is not going to cause a maneuver the pilot can't recover from with a reasonable delay. So the pilot, if the autopilot is flying both a pitch and roll axis, for instance, we take -- take, for example, the roll axis. We put enough voltage on the servo of the autopilot to saturate it. In other words, more than it needs to go to full deflection.

So it goes full deflection as much as it can as quick as it can and stays there. And so, hardover means as far as the controls and as far a direction as they'll go as quick as they can move. And that's basically what we're talking about for a hardover.

CHAIRMAN HALL: Thank you.

THE WITNESS: The rudder hardover rates then, basically these tests were done by allowing the rudder to go to full deflection but at the rate shown. And the intent of doing these as different failure rates was to try to match or look at the departure rates shown on the FDR to see if we could come up with something that was similar that way.

Coincidentally, the first one, Number A, is basically the same rudder hardover failure rate that you would get with a trim runaway, a rudder trim runaway, which is electric in this airplane. So the initial reaction would be the same, although with a trim runaway, which we also did, the rudder only goes to 13 degrees instead of full over.

MR. JACKY: And why is that?

THE WITNESS: Because the rudder trim is limited to a maximum authority of about a little more than half deflection, because basically you don't need any more rudder trim than that. To trim the engine, to trim the -- I think the maximum rudder trim requirement is with engine out, the engine out requirement at 1.4 times the stall speed. So basically, you don't make the controls any more powerful than they need to be because of the possibility of it running away like that.

For example, on the aileron trim and on the rudder trim, in flight tests if you can't disconnect an autopilot or electronic augmentation system, we require that it runs all the way to the stop and then we react to it. So basically, for a rudder trim hardover, we're running all the way to 14 degrees and for an aileron trim runaway, we'll run it as far as it can go and then it's sure that the pilot can make a continued safe flight and landing without any problem.

So that's why it's limited to a certain number of degrees. If it does run away, you don't want it to cause a problem.

MR. JACKY: So in your flight certification tests, you would be more apt to test the runaway rates of the trims of the control surfaces as opposed to testing for the full travel of the surface itself?

THE WITNESS: That's correct. Basically, we know that there are failure rates in electronic augmentation systems and autopilots. Based on our experience we know that it's going to happen. So basically, we want to assure ourselves that there are no hazardous characteristics involved with an autopilot hardover or any kind of electronic augmentation hardover.

We discovered as we were doing this that the maximum roll rate that was achieved as a function of the rudder hardover rates was pretty much a one to one relationship. In other words, if you put the rudder in at a faster rate, the airplane rolled at a faster rate. And we discovered that.

In truth, what was said before was true, that if you do it very, very slowly and stabilize the airplane in a straight ahead side slip, the rudder and ailerons are exactly equal at 190 knots and flaps one. However, if you put the rudder in at any rate, then basically the rudder will roll the airplane faster than the aileron will.

And so we discovered that the hardover rate here, the maximum rate that you would achieve is pretty much proportional to the rudder hardover rate. And the data that we got from the Performance Group shows that a half a second -- half a degree per second hardover rate shows only about -- the airplane would roll 70 degrees in 17 seconds, which is pretty slow. It's an average of about 4 degrees per second.

And you work your way up that way and then you find out that at 2-1/2 degrees per second it rolls 75 degrees in 7-1/2 seconds, which is up to 10 already, and it progresses all the way down pretty much linearly until you get the maximum rate, which is just basically to stomp the rudder all the way to the floor at 52 degrees per second. At that point, the rudder rolls the airplane due to the dihedral effect we were talking about at about a maximum rate of 32 degrees per second.

There's some additional data later on, too, that shows the aileron only, but basically what we're looking here at the rudder hardover rates and the roll rate of the airplane and the reaction of the airplane based on those.

MR. JACKY: Was I correct? You just said you discovered something regarding the rudder roll rate?

THE WITNESS: The roll rate of the airplane due to the rudder, yes. In other words, we talked about -- yesterday, Mr. Kerrigan explained what the roll due to the side slip was caused by. And if you have a swept wing airplane with the wings like this, if you yaw the airplane like this, the wing on the right, for instance, if you're yawing nose left, the wing here is more perpendicular into the wind and the trailing wing is farther back. So therefore, you have more lift on this wing than you have on that one. And that's a static characteristic. So that if you're just stabilized there with just rudder and aileron holding it, that's the characteristic you have.

There are two other factors, however, involved in that. One is the side slip overshoot when you're using a dynamic rudder input, and the second one is the fact that you roll also due to yaw rate. In other words, when the airplane is yawing like this, the wing on the outside has a slightly higher velocity than the one that's going back. So that causes a little bit higher dynamic pressure and a little bit more roll.

Secondly, when you put the rudder in at a high rate, the side slip that you get, you get kind of an overshoot due to the momentum of the maneuver so that your side slip goes way up higher and then it will eventually stabilize that, and therefore, causes a higher roll rate initially due to a dynamic input than you would have if you just put it in slowly and held it statically.

So that's when you get an increasing roll rate due to the rudder input rate.

MR. JACKY: And you weren't aware of that prior to these tests?

THE WITNESS: Yes. We were aware of that. And all airplanes do the very same thing. It's nothing that's particular to the Boeing 737. All other swept wing airplanes do it, too.

MR. JACKY: So rather than discover, you're basically verifying those --

THE WITNESS: Pardon?

MR. JACKY: Rather than discovering, you were actually verifying those results?

THE WITNESS: Yes. Basically, we knew that the characteristic existed. What we were trying to do here now is quantify it; how much and what's the relationship between the roll rate due to the rudder and the roll rate due to the ailerons which could oppose it.

MR. JACKY: In looking at the rudder hardover rates listed there, A through F, you may have already done so, but could you characterize any of the rates as being what you would believe or in your experience would be consistent with the FDR data shown off of USAir 427?

THE WITNESS: It really wasn't possible to match it exactly, but as far as I can remember, the 2-1/2 degree per second was about the closest one, 2-1/2 to 3 degrees per second. Again, it didn't match it exactly but it was closer than any others.

MR. JACKY: Let me rephrase that. In looking at just the initial first five or six seconds of the upset, which one of those rudder rates do you believe might or in your experience would most closely match the FDR data?

THE WITNESS: I'd say it was 2-1/2 degrees per second.

MR. JACKY: Okay. Moving on, in looking at test Number 3, could you please explain that test and --

THE WITNESS: Well, there was one other thing we did here, too, that I forgot to talk about. It was the maximum, the yaw damper input. That was a slightly different test in that the yaw damper itself has very much little or very much less authority than the basic rudder does. The rudder in a static deflection will on the ground deflect 26 degrees and in flight, at these flight conditions, it will deflect approximately 19 to 20 because the air forces blow the rudder back and the yaw damper in this case is only going to deflect about 30 degrees.

So the roll rate due to yaw damper output at full deflection hardover is really quite benign. I think the airplane only rolls about 15-16 degrees per yaw damper hardover.

CHAIRMAN HALL: Again, -- you do such a good job of explaining, sir. If you give us just an elementary discussion of what the yaw damper does, I'd appreciate it.

THE WITNESS: Okay. Basically, the vertical fin on an airplane acts like the feathers on an arrow, so that if you're flying along there and the pilot is not making an input and a gust upsets the airplane laterally or directionally, like this, there's a wind blowing on the opposite side of the rudder that pushes it back around into the -- straight into the wind. On slow speed airplanes and straight wind airplanes, that does a pretty good job. But when you get to a swept wing airplane and high wing loadings and high altitudes and mach numbers, the arrow, the feathers on the arrow are not quite as effective and you have to get to a bigger angle before it will blow it back.

And so what you wind up with is an airplane that wanders back and forth like this, left and right, getting to a big enough angle that it will blow the rudder back and straighten out the airplane. That's the Dutch roll mode we talked about because when it does this little snaking motion, we're talking about the roll due to yaw, it does a little bit of a roll, too, and it's kind of out of phase by 90 degrees and it kind of wanders back and forth like this. It's more of a nuisance than anything else, but typically every major large jet transport has a yaw damper which is a very quick reaction, automatic electronic system, that moves the rudder quickly and stops this without the pilot having to do anything with it.

CHAIRMAN HALL: And that can be controlled by the autopilot?

THE WITNESS: It's controlled by a separate unit called a yaw damper.

CHAIRMAN HALL: Thank you.

MR. JACKY: Just a follow-up question. The yaw damper is not part of the autopilot system in the 737-300 aircraft?

THE WITNESS: I believe it is separate. Yes.

MR. JACKY: If you could get or, please, if we could return to Item Number 3 and describe that test, please.

THE WITNESS: Basically what this was was input the rudder hardover, full deflection; don't make any pilot input until the airplane rolls to about 80 degrees and then pull the column back into the stickshaker. This is kind of one of many scenarios we looked at to see what the aircraft response would be to this kind of maneuver and basically the data that I looked at, this is one where we left the autopilot on and didn't disconnect it. It was somewhat similar to the FDR trace.

The airplane goes all the way over and rolls more than 360 degrees and back up to another 100 degrees. So it doesn't represent the FDR trace but it is a significant departure from control flight.

MR. JACKY: And Item Number 4?

THE WITNESS: Basically, I guess a general comment I would have, that all of these other failures were benign. The only one that was really significant was the rudder input.

The leading edge asymmetry with or without auto-slats -- in other words, we put the leading edges out on one side and then sling all the way down to the stall on the airplane and the airplane rolls off, of course, to about 70-80 degrees, which is what you would expect. But it was controllable, recoverable.

On the next one, we have an auto-slat misfire at the stickshaker, and I think that was from flaps 5 where the auto-slat starts to work. And what does is when you slow down, you get into or just beyond stickshaker, the leading edge devices extend automatically, called auto-slats. And so we failed one of those and had one come out and one not come out. And that again, was pretty minor maneuver. It only rolls about 10 degrees.

Number 6 is basically the same as Number 3 up there and does the same thing.

MR. JACKY: And Number 7, Mr. Kerrigan spoke to yesterday.

THE WITNESS: Yes.

MR. JACKY: And I believe that Number 8 and Number 10 are relatively the same?

THE WITNESS: Yes.

MR. JACKY: Could you discuss Number 10 then please?

THE WITNESS: Okay. Did you say Number 9 or Number 10?

MR. JACKY: I said Number 10.

THE WITNESS: Okay.

MR. JACKY: Just skip Number 8, basically.

THE WITNESS: Okay. On Number 10, what we were looking there was the aileron rudder trades from a dynamic input. We wanted to see what the maximum roll rate was using just the lateral control system, just the rudder system, and then how much roll you could get with them both used together hardover as quick as they could move and then what would happen if you used them in opposition.

Basically, what you have on the wheel input rate for the data we got in the Performance Group, if you don't use any rudder at all and just slam the wheel hardover as far as it will go and hold it there, the maximum rate that you reach is about 23 degrees per second, and that's normal for the 737. Because basically when you do that without the rudder input, the ailerons, in conjunction with the spoilers, wind up with a slight adverse yaw. The nose doesn't turn into the turn as quick as it would if you used coordinated rudder, so you get a little bit of adverse and you don't rolls quite as fast with ailerons only.

With all the other controls free with a rudder input rate of full deflection as quick as you could move, it rolled to a maximum rate of about 30 -- a little more than 30-32 degrees per second.

Now, the next one where we did combined wheel and rudder hardovers in the same direction, in other words, you slam it over full rudder deflection and full aileron deflection into the turn into the same direction, you got amazingly enough, pretty much the sum of those two, which is about 55 degrees per second.

When we did the adverse inputs, in other words, it was rudder to the left, wheel to the right, full deflection over like that, the airplane initially did roll into the rudder because of the large side slip that you built up. It overpowers the ailerons at the beginning of the maneuver, but once this initial side slip has damped out due to the stability, you wind up with a maximum rate of about 17 degrees per second. And then once you reach a bank angle of 40 degrees, the airplane stops rolling and the balance of forces are such that you're out of the dynamic case and now back into the static case and the rudder and ailerons are balanced.

MR. JACKY: And finally, if you could describe the test in Number 9, please?

THE WITNESS: This was one of just many tests we looked at just to get a general picture of the characteristics of the airplane in all the kind of combinations and permutations we could come up with and this is one of the -- a rudder input hardover with limited lateral control. In other words, they turned off the roll spoilers and you had ailerons only. And as I recall, in this condition of about flaps 1 and 190, the ailerons and the spoilers are just about the same effectiveness.

So if you turn off the roll spoilers, you basically have half the lateral control power that you had previously. So in this case, with the rudder hardover to the left, the airplane basically rolls considerably faster to the left than it would normally. And the maneuver in this case was basically the same thing we got before. It was the nose dropping and the airplane rolling, but it rolled so fast that it completed the roll and wound up with about 45 or 60 degrees nose down, continuing to roll.

MR. JACKY: Thank you.

I wanted to ask you a couple of questions regarding some of the simulations of the wake vortex modeling. Let me ask first of all, did you participate in those simulator sessions?

THE WITNESS: Yes, I did. I flew quite a few of those.

MR. JACKY: And what was your general impression of the wake vortex as modeled by Boeing engineers?

THE WITNESS: I thought it was quite a good simulation. In my flight experience I've probably encountered 10 or 15 of these things at all different angles; straight across, straight up, in landing configuration and whatever, including in the 737. And I thought it was an excellent simulation. It felt just like it would in the real airplane.

MR. JACKY: And how would that feel in a real airplane?

THE WITNESS: Basically, it depends on the angle you cross the vortex at and how strong it is, but typically a large crossing angle, in other words, perpendicular to the vortex stream, is basically a very hard hit but not much G. Say 3/10 of a G. And typically it's very, very sharp, so it's like somebody hit the bottom of the airplane with a baseball bat.

It's a jolt. And you say, "Wow, what was that?"

The more you turn parallel to the vortex stream, the more roll you get out of it, so that if you slide into one parallel like this, basically if it's a strong vortex and you're very close behind the airplane, it typically will just take the airplane and yaw and roll it quickly like that. Zow. And you wind up typically in a 737 no more than about a 30 degree bank. It rolls very fast but not very long. And it spits you out one side of the vortex and you wind up at a maximum of about a 30 degree bank.

MR. JACKY: And could you characterize the Boeing distributed lift model that they made for the 737?

THE WITNESS: I didn't look at particularly the data itself, but the airplane in the simulator certainly flew a lot like the 737. And again, I say that the vortex interactions with the 737 felt just like I've experienced it in flight.

MR. JACKY: Do you believe that the simulator aircraft flew with the distributed lift model off compared to the -- let me rephrase that.

The simulator aircraft with the distributed lift model flown on -- or turned on, and with the distributed lift model turned off, did you feel that the reaction or the flying characteristics of the airplane were similar?

THE WITNESS: I don't think you can tell the difference unless you're doing something like a vortex interaction. Normally, flying around, what they mean by a non-distributed lift model is they just put the lift on one wing at the aerodynamic center of the wing. It's the correct lift and the correct rolling moment, so it feels normal to the pilot.

What they're saying is that you have to use the distributed lift model where you segment the lift across the wing and then integrate it, because what you have is you have the vortex interacting with only part of the wing, not the whole wing.

So what they wanted to show was the incremental increase in the roll rate as you moved into the vortex. So you couldn't tell the difference between a distributed lift model and a non-distributed lift model if you weren't entering a vortex.

MR. JACKY: You had previously described the yaw damper and the yaw damper operation in the 737-300. As a pilot, can you notice yaw damper input during flight, normal flight?

THE WITNESS: Not really. Once you turn the yaw damper on, it basically just does its job and keeps the airplane from fishtailing. It makes the airplane fly straight like it's supposed to. It's a series yaw damper, which means that when the yaw damper moves the rudder, it doesn't move the pedals, so it's doing its job, transparent to the pilot.

MR. JACKY: In your experience, would you expect yaw damper input during the wake vortex encounter?

THE WITNESS: Yes. And it would depend, I guess, on how you entered the vortex. Typically, the ones that we saw in the distributed lift model in the vortex simulation, if you went straight in it from the side, it was mostly roll and not much yaw. If you came at it from the bottom where you hit the vertical fin first, it did yaw.

And basically what the yaw damper does, it has a rate gyro on the back and it senses rate and puts in rudder to stop that rate motion. So if anything pushes on the rudder, a lateral gust or a vortex encounter and it starts to yaw the airplane at a yaw rate, basically the yaw damper says -- put an opposite rudder to stop that rate.

So, yes, if you were in a vortex and you continued to yaw, the yaw damper would put in as much authority as it had until it stopped the yaw rate or it was full deflection.

MR. JACKY: I meant to ask you a question about your wake vortex encounter experience. When you -- or how would you know that you had experienced a wake vortex?

THE WITNESS: It's pretty unmistakable. Basically, it's nothing like you encounter in normal flight. It basically feels like some giant hand grabbed the airplane and just took it right away from you and moved it one direction or another. It's a bit disconcerting, but --

MR. JACKY: Can you characterize the length of time of this episode in general?

THE WITNESS: In the ones I've seen, I've never seen it last more than just a second or two, two seconds at the most. The ones that we saw on the distributed lift model and the vortex here were -- typically when you're out there flying around in the real world you don't hit both vortexes. They come off the wing and they go down and they split. So typically, you're not going to see both of the vortexes. You're only going to run into one of them and it's going just quick roll you up and spit you out the side or just give you a bump as you go across it.

On the distributed lift model and vortex interaction tests that we did in the simulator, we had it set up so that you would go through both of them to look at the worst case. And basically, it was very difficult, even though the vortexes are actually visual. You had to be very careful to get right in the middle of it or it would just spit you out the top, bottom or out one side.

It takes two or three tries to even get into it. And the one that we finally did that looked real good is we went in the left side vortex. It rolls the airplane like this to the right, back, to the right, and you come out the other side. And even with the autopilot on, it could control the airplane and the bank didn't get more than about 25 degrees.

But the typical, I think it was 1500 feet squared per second vortex which we thought was the most representative.

CHAIRMAN HALL: Mr. Jacky, if I might just ask a question here. On the 737, how much authority does the yaw damper have?

THE WITNESS: Well, it controls three degrees out of the 26, so it's not a very high authority system.

MR. JACKY: Does the FAA require pilots to go through any sort of wake vortex encounter training?

THE WITNESS: Not that I know of. There are some good write-ups in the Airman's Information Manual and I'm sure that -- I can just presume that the airlines have some information on that. But there's no formal training that I know of.

I'm not sure exactly what you would do. You'd have to just say stay out of it, because it happens so quick there's nothing you can do about it anyway. You're in and out of it in a second or two. So the best thing is to keep yourself from getting into one and there's some techniques that are recommended on how to do that; Advisory Circulars and the Airman's Information Manual.

MR. JACKY: Does the FAA plan on asking Boeing to perform any sort of flight tests in regards to this accident?

THE WITNESS: Not at this time.

MR. JACKY: I have no further questions.

CHAIRMAN HALL: Thank you, Mr. Jacky.

Do any of the parties have questions?

I only see a hand from the Airline Pilot's Association. Anyone else?

(No response.)

If not, Captain, your question, please.

CAPTAIN LeGROW: Thank you, Mr. Chairman.

Good morning, Mr. Berven.

THE WITNESS: Hi.

CAPTAIN LeGROW: I have just a couple of questions.

First of all, when the FAA does a certification or did the certification on the 737-300, did they do a new aircraft certification test?

THE WITNESS: Basically, yes. There were enough changes in the airplane. The lengthening of the fuselage and the different engines, the different material in the elevators and different cockpit, different instrumentation, that basically -- the stuff that I'm involved in is called Subpart B, which is performance and flying qualities, and we did every one of those all over again. And the systems tests that were changed were basically -- most all of them, we did those also.

So it was essentially a new certification program.

CAPTAIN LeGROW: So it wasn't grandfathered in in the previous models. It had a full new aircraft certification?

THE WITNESS: Yes, it did.

CAPTAIN LeGROW: Thank you.

THE WITNESS: I believe the original certification basis was still used, but we did the test that we would do on basically a new airplane.

CAPTAIN LeGROW: Thank you.

On the wake vortex, were you here yesterday for Mr. Green's testimony and Mr. Kerrigan's testimony?

THE WITNESS: Yes, I was.

CAPTAIN LeGROW: Both -- Mr. Green testified, if you recall, that the most he would expect in a wake vortex encounter would be 30 degrees and I think you testified the same thing here when Mr. Jacky was questioning you.

THE WITNESS: Yes.

CAPTAIN LeGROW: You also said that the most you'd expect would be 30 degrees in a strong vortex. Could you define strong vortex, please?

THE WITNESS: I would say a strong vortex, you know, is one that's where you're reasonable close behind another airplane, like minimum separation. And it's on a calm day and you're flying right through the middle of it and it hasn't dissipated or started to break up due to turbulence, so it's kind of a fresh vortex and your minimum separation about another heavy airplane.

CAPTAIN LeGROW: Could you tell us what minimum separation between a 737 and 727 would be?

THE WITNESS: I really don't remember. I don't know. Three miles?

CAPTAIN LeGROW: Three miles.

THE WITNESS: I think so.

CAPTAIN LeGROW: So if a 737 were four or more miles behind a 727, you'd expect something less than a 30 degree bank? Would that be a fair statement?

THE WITNESS: I really don't know. There's so much variation and atmospheric dynamics that you couldn't -- I don't think I could really say that.

I've seen, you know, you never -- I've seen conditions where I never knew the airplane was even there but I flew into it and it was kind of wiggle like that. You know, five or 10 degrees. I knew it was a vortex but I didn't know how old it was. I didn't even see the airplane.

CAPTAIN LeGROW: Would it be safe to say that you wouldn't expect 50 degrees of bank as represented in Boeing's vortex video yesterday?

THE WITNESS: I never saw that in the

simulator test that I did.

CAPTAIN LeGROW: Thank you.

I have no further questions.

CHAIRMAN HALL: Any other questions from any of the parties?

Does Boeing have any questions for this witness? FAA?

If not, Mr. Marx.

MR. MARX: Mr. Berven, could you explain to me when you would use rudder during a flight and what operations would you use it other than engine out? A pilot, pilot input to the rudders.

THE WITNESS: Typically for a jet transport or any type of jet airplane, the rudder is the least used flight control. Typically, you use it for taxiing and only if the engine is out. And sometimes you also use it, depending on your technique, if you're landing in a heavy crosswind. In that technique, basically, you come down -- if you have a hard crosswind, say from the left, you bank the airplane to the left so that the left vector cancels the drift of the crosswind and then you use the opposite rudder to keep the airplane parallel to the direction of motion and you land it on one wheel so that you don't get side forces on touchdown.

So, for engine out, crosswinds and taxiing is typically when you would use it.

MR. MARX: During the flight regime of 427 at the time of the upset, would you expect any of the crew members to be using rudder at all at this time?

THE WITNESS: No. I believe they were on autopilot.

MR. MARX: If a wake vortex is encountered in which there is a real upset of the airplane, what are the pilots trained to do, or in your experience what would you do as far as the rudders are concerned?

THE WITNESS: As far as the rudder?

MR. MARX: Rudder. Would you put any rudder input into it?

THE WITNESS: Probably not because you typically in a quick reaction situation or in an emergency like that, you're not going to do anything that you haven't already been doing. If you had enough to react or a couple of seconds and you were in a steady yaw, then you'd bring it back. But my reaction when I run into a rolling vortex like that is just to put the ailerons over real quick and stop the roll. But it's so quick. You know, you're only in it a second or two that you just oppose it as much as you can with the aileron and it spits you out the side.

I don't think you would have time to think about using the rudder. It might be instinctive, but I don't know.

MR. MARX: Well, do you know of any training where they would be training pilots to use rudder in that situation?

THE WITNESS: No. I don't know.

MR. MARX: The exhibit that's up, the viewgraph that's up there right now, you were speaking to adverse rates where you take the rudder and move it in one direction and the wheel in the opposite direction.

I was a little bit confused. Maybe you can explain it a little bit, but let's assume that we had left rudder, full left rudder at the maximum rate and we had full wheel compensating at its maximum rate to the right. My understanding is that you said something about 17 degrees per second in the direction of rudder. Is that right? I mean, as if the rudder was -- it was rolling in the direction of left roll?

THE WITNESS: That's correct.

MR. MARX: Okay.

THE WITNESS: It rolls into the direction of the rudder initially.

MR. MARX: Because the rudder was more powerful because of the fact that it's at a faster rate?

THE WITNESS: Well, yes. Because of the dynamic input of the rudder. But once that dynamic input is over and the side that peaks and comes back down to some lower value, then they usually balance out. And the airplane, it rolls and winds up at about a 45 degree stabilized bank for that condition.

MR. MARX: Would the autopilot be -- let's assume that we would have a full left rudder deflection for some reason and it was on autopilot. Would the autopilot continue to control the airplane?

THE WITNESS: Well, the autopilot would

attempt to control the airplane but like the yaw damper, the autopilot doesn't have full roll control authority. It can't use full control deflection. I think it only uses about 40 percent of the aileron.

So it -- in fact, when you do this maneuver with the autopilot on, it rapidly puts the wheel opposite to the roll in the direction of the rudder, but it only uses about 40 to 50 percent of the roll deflection so that the airplane continues to roll rapidly into the rudder.

MR. MARX: Well, when you're on autopilot though, would you expect the autopilot to compensate the aircraft? I mean, at what point in time would you know that you'd be getting into trouble with an airplane?

THE WITNESS: Well, basically, like I said, when we do an autopilot hardover, we require that for a maximum rate input of a failure that affects the attitudes of the airplane, that from pilot reaction and three second later, it not roll any faster such that you wind up more than a 60 degree bank. And what happens when you do it with the autopilot on in this maneuver is that it rolls very, very rapidly.

So, if you assume that the pilot is basically doing his normal duties, you know, watching for airplanes and using basically the navigation and the ATC functions, if something like a full rudder hardover occurred, you would notice immediately that something was happening at the minute the airplane started to roll. But it would take a couple of seconds to figure out if in fact it was just a gust or something else was going on.

And if you look at it, let's say representative from what we saw in the simulator, the airplane typically rolls to about 40 to 50 degrees before you've figured it out and have disconnected the autopilot. And at that point, you put the rest of the aileron and it still continues to roll over to a steep angle.

If you put the aileron in immediately, if you disconnect the autopilot and slam it over as far as you can go quickly, the airplane rolls to about 90 to 100 degrees and the nose drops to about 60, but you can pull it back out. If you don't put in full aileron immediately or if there's any delay in putting in additional aileron, then it rolls all the way on over.

So the autopilot itself can't be designed essentially for full 100 percent authority or they couldn't pass the failure case. So the autopilot is only about half authority or less. You'd only use half wheel. But it did put in all it could.

MR. MARX: And you're also speaking of a situation in a simulator where a pilot was putting in full left or full right rudder control and what have you and then catching it with aileron control. I think you spoke of that in the beginning of your testimony.

I guess one of the questions I would have is surprise. Whether a person is expecting this type of thing to occur and the amount of time it takes to recognize that you have a problem and to cause a correction. And you were speaking before of about a three second reaction time to occur.

Was this the type of stuff that this pilot was taking into account? The fact that he would have to have three seconds to react to this?

THE WITNESS: I guess I don't understand the question.

MR. MARX: Well, the question is if you're simulating a condition where he is putting a hardover rudder into the simulator and then correcting with roll, he was able to keep it -- my understanding was that he was able to keep it from rolling over on its back.

THE WITNESS: Oh, I see what your question is.

MR. MARX: Yes. Now, he was assuming -- he knew that this was coming.

THE WITNESS: Right.

MR. MARX: If you took into effect that you didn't know it was coming and you had a reaction time of three seconds to react to it, would you expect the same result?

THE WITNESS: I would say no. If in fact -- we were basically disconnecting the thing at 50 to 60 degrees, which is basically when we got to it. There was no intentional delay. If you catch it at 50 degrees and disconnect immediately and slam the ailerons over, you can keep it up between 90 and 100 degrees.

I looked at some of the other data basically and on the ones where you did the maximum rate hardover and didn't put the ailerons in, if you waited four seconds from the initiation of the failures, which is basically what the Europeans do, they don't wait until pilot recognition plus three. They just say it's one second. It takes half a second to get the failure in and half a second for the pilot to recognize it.

So if you do this maneuver assuming four seconds from a hardover rudder with no pilot input like you would do for an autopilot test, the airplane rolls to about 120 degrees.

MR. MARX: That's over on its back.

THE WITNESS: Yes.

MR. MARX: Well, once again, I didn't finish the question I had before with the 17 degrees left roll -- 17 degrees per second when we were talking about the adverse rate. That's the initial adverse rate. Is there -- when you say initial, does that mean at the very onset of the roll or are you talking about through the roll, complete roll, to get to a certain degree?

In other words, is there an average? Would it slow down? Would it start at 17 degrees per second and go to five degrees per second and have an average roll?

THE WITNESS: Well, basically the roll rate has to build up. It's kind of a smooth curve. When you first put in the rudder and opposite aileron it's pretty much a smooth curve. It's parabolic. It goes like this and accelerates and so that it comes down to a maximum point. And that's what I'm talking about was the maximum roll rate, which occurs -- it's a function of the roll damping of the airplane and the amount of control input. But it typically takes about a second to a second and a half to maximum roll rate.

MR. MARX: What was the roll rate on the actual accident airplane, this 427? Would it correspond to that?

THE WITNESS: I remember that it's something like around 10 to 12 degrees per second.

MR. MARX: Was the roll rate for the 427?

THE WITNESS: Yes.

MR. MARX: All right. Just one other thing

I'd like to -- the business with the degree per second hardover on the rudder, we've heard testimony dealing with five degrees per second, I think, from the Boeing representative and you indicated about a 2-1/2 degrees per second rate of change of rudder.

I don't know. Is this based -- the 2-1/2 degrees per second is based on what data? Boeing data?

THE WITNESS: You're talking about the comparison to the FDR? What I said was that initially we tried to match the heading rate. In other words, as the airplane departed, it does the same thing. It builds up to a certain rate and then comes back down like this. So we're looking at -- if you put the rudder in at 2-1/2 degrees per second, I'm just saying that at a 2-1/2 degree per second hardover, the shape of the heading departure looks the same. It doesn't match it exactly but it's fairly close.

MR. MARX: That's with the full wheel deflection that's trying to --

THE WITNESS: No. That's just the full rudder.

MR. MARX: That's just full rudder?

THE WITNESS: Yes.

MR. MARX: So that's just a side slip?

THE WITNESS: It's a roll due to the side slip and the yaw rate.

MR. MARX: I have no further questions.

CHAIRMAN HALL: Mr. Clark?

MR. CLARK: Mr. Berven, earlier there was a discussion about steady heading side slip tests. And in that, I think I misunderstood. I thought you said that you don't test to full flight control input.

THE WITNESS: Not dynamically. We do statically. In other words, we stabilize very slowly until we reach full control deflection to see that the rudder doesn't what I'll call overbalance or come up with some reverse in the hitch moment. And also that the aileron forces are proportional to the side slope.

MR. CLARK: Okay. That's what I meant.

THE WITNESS: We do go to full deflection but not rapidly.

MR. CLARK: Okay. Thank you.

One other questions. In your experience with your encounters with flight vortices and with the simulation experience, would you expect the 737 to be upset by the wake of a 727?

MR. CLARK: Not more than 30 degrees.

MR. CLARK: That's all I have. Thank you.

CHAIRMAN HALL: Mr. Schleede?

MR. SCHLEEDE: Thank you.

Mr. Berven, we're going to have some testimony later in detail about the yaw damper system on the 737. I wanted to ask you a few questions about that before you get off.

Have you experienced maximum rate step input yaw damper failures in flight?

THE WITNESS: Yes, I have. Intentionally for the flight testing, but primarily the original test that I did was in the 727-200, which was -- where the S piece at 177 autopilot, which in fact should be worse, because it was a four degree yaw damper at the time and a lighter airplane.

Typically, the characteristics there are it's a function of airspeed pretty much. In the approach mode, for instance, if you're making a auto land and you have a yaw damper hardover, it's hardly noticeable.

The autopilot rolls up about two to three degrees and continues on to the auto land. It's just very benign.

On the other end of the spectrum up at VMO, which is 365 knots indicated, I believe, it's a little more of a reaction of the airplane. I believe for the data shown there that you get about a third of the G, lateral bump, so it jerks you off to the side and the airplane rolled -- I believe it was 45 degrees with pilot reaction. No. It was 49 degrees if they didn't disconnect the yaw damper and 42 degrees if they did. And that's with the three second delay from pilot reaction.

In the middle range or the slow speed, like we're talking about with flaps 1 and 190, the typical hardover is very benign. It only rolls about 20 degrees or less.

MR. SCHLEEDE: Is that assuming a three second response?

THE WITNESS: That's with a three second delay after pilot reaction.

MR. SCHLEEDE: Regarding that system you mentioned about turning it off, what is the procedure for response to a yaw damper malfunction?

THE WITNESS: I don't believe -- I guess I don't know. In flight tests basically we just oppose it with the rudder after the three second delay. We use aileron and rudder to recover from it.

MR. SCHLEEDE: Does the yaw damper, this type of a malfunction something that's considered during your responsibilities in flight tests for handling qualities?

THE WITNESS: Yes.

MR. SCHLEEDE: Is it something that's considered for certification of the aircraft?

THE WITNESS: Yes. We do that as a part of the automatic flight control system evaluation. We do autopilot hardovers and yaw damper hardovers throughout the flight envelope of the airplane.

MR. SCHLEEDE: How would you characterize step input yaw damper malfunctions? Would you consider them a safety problem for flight safety?

THE WITNESS: I guess depending on where you were and whether you were standing up or not. At cruise flight with a yard damper hardover, it will knock you over if you're in the back of the airplane, but it's not a hazard from the safety standpoint of the airplane, no. It not an uncontrollable maneuver for the pilot, although it is uncomfortable and quite a good jerk.

MR. SCHLEEDE: Have you participated in 737 flight tests of thrust reverse deployments in flight?

THE WITNESS: Yes, I have.

MR. SCHLEEDE: Can you describe those briefly for us?

THE WITNESS: Basically, the maneuver we do, -- if I can remember this. The maneuver we do is basically to assure that if the thrust reverse comes out that you can continue with safe flight and landing. And we do this at about -- I believe it was about 200 knots where we put a -- and normally you can't do that because it's locked out due to the air ground switch. But we put in a modification to allow us to do that. So, we stabilized the airplane at idle on one engine and around 200 knots -- it varies with the airplane -- and extend the thrust reverse to its full deflected position with the engine at idle. And we look at the operational characteristics of the airplane; whereas, how much roll, how much yaw, how much buffet.

And basically, we only do that at idle because there's basically what we call a throttle snatcher in the control system such that if the reverse unlocks, it pulls the idle -- the throttle, all the way back to idle immediately.

So we look at that characteristic and, depending on the airplane, -- as I remember on the 737 it's not a significant problem. There is some buffet and roll but you can continue the airplane, continue safe flight and landing even if you don't shut the engine down.

MR. CLARK: And this throttle snatcher, is that system installed on the 737-300?

THE WITNESS: Yes. I believe so.

MR. SCHLEEDE: During those various tests that you described with Mr. Jacky and the hardover simulations, did you note anything that would cause you to question any of the decisions made on the original certification of this airplane?

THE WITNESS: No, not at all. The aircraft met all of the airworthiness rules handily and really flies quite nicely.

MR. SCHLEEDE: Thank you very much.

CHAIRMAN HALL: Mr. Laynor?

MR. LAYNOR: Just a couple, Mr. Berven. I think clarification.

I'm not quite sure I understood the extent to which you test hardover flight controls beyond the autopilot authority. I think you said you did not test dynamically but you did test statically.

What regulatory requirements assure protection against a non-tested control deflection?

THE WITNESS: I'm not an expert on failure modes and effects analysis, but based on my basic knowledge and what I think that happens on this airplane is that basically the flight control systems aren't tested. The primary flight controls are not tested for hardover testing because they have so much control power by the nature of the design that you could lose the airplane if you do that.

Therefore, the initial intent is that you can't have that happen. Basically, the flight control systems have to be as safe and prevented from hardovers as the basic structure of the airplane.

I believe that the certification basis for the 737 says that you can't have any single failure or any latent failure plus one more that would cause you not to be able to continue safe flight and landing. And basically, their failure analysis shows that.

So our impression is that a primary flight control system hardover is impossible and has to be impossible.

MR. SCHLEEDE: Okay. So it's airworthiness redundancy requirements that are the protection.

Is the yaw damper a required piece of equipment in the 737 per dispatch?

THE WITNESS: I believe it is. And you can dispatch it to a certain altitude, but I'm not an expert on that. I don't remember. I think it is required.

MR. SCHLEEDE: Are the handling qualities of the airplane satisfactory without the yaw damper for normal landing, takeoff and cruise situations?

THE WITNESS: Yes, they are.

MR. SCHLEEDE: You mentioned yaw damper hardover. It would typically, perhaps roll the airplane to about 15 degrees before the pilot reacted and stopped that roll.

Now, you didn't say what kind of roll rate might be associated with that. Is that --

THE WITNESS: I really don't know what that would be. You're looking at a very non-linear event there. Just about the time the roll rate peaks is when you recover, so it's basically continuously changing from zero to whatever the maximum would be and you'd wind up with an average that would give you essentially 15 degrees in 3-1/3 seconds, whatever that is. It's not very fast.

MR. SCHLEEDE: All right. And only one more for clarification.

In the description for the exhibit that's still up on the screen back there, what speed were the roll rate tests made that were described under Number 10 on that exhibit?

THE WITNESS: These are all done at 190 knots with flaps 1.

MR. SCHLEEDE: 190 and with flaps at 1?

THE WITNESS: That's right.

MR. SCHLEEDE: Okay. The accident condition?

THE WITNESS: That's correct.

MR. SCHLEEDE: Thank you very much, Mr. Berven.

CHAIRMAN HALL: Again, just a few questions. I appreciate your time up here.

You earlier described a side slip and I believe the accident flight itself was in a turn, it appears, at the time this encounter happened. How does a side slip or a turn affect the authority of the yaw damper or the rudder in a hardover?

THE WITNESS: I guess I don't understand that question. Typically in a turn the autopilot, basically the airplane is flying pretty narrow at zero side slip, so that autopilot -- the yaw dampers is working plus or minus about that to keep it at zero, to keep the yaw rate to zero in any case.

CHAIRMAN HALL: In a side slip you wouldn't get any more authority out of the yaw damper in terms of --

THE WITNESS: No. It would be the same.

CHAIRMAN HALL: It would be the same. Okay.

Is there anything in your opinion besides the rudder that could give a roll rate consistent with the trace on the flight data recorder?

THE WITNESS: Based on all the testing we did, that was the only control that would cause it to roll that fast.

CHAIRMAN HALL: Okay. And let me see. Your testing that you do for certification, do you have the autopilot on when you try these hardovers or are you hand flying the plane?

THE WITNESS: Well, we don't do any hardovers with the autopilot off. As I pointed out, we don't do primary flight condition hardovers. When we do the autopilot hardovers, we're not -- we have no hands on the controls. Basically, we're using a stopwatch. Somebody in the back initiates the yaw damper servo hardover and I wait until I see something and then I count mark 1002, 1003 and then recover from whatever maneuver that they input.

What you typically do at the end of that three seconds, you disconnect the autopilot and then recover back to level flight.

CHAIRMAN HALL: Mr. Berven, in my opinion you have done an excellent job of representing the Federal Aviation Administration. You've been a good witness. Thank you very much. You're excused.

THE WITNESS: Thank you.

(Witness excused.)

CHAIRMAN HALL: The next witness we will call is Mr. Michael Carriker. If Mr. Carriker could approach, he is a Senior Engineering Project Pilot on the 737. He is with the Boeing Commercial Airplane Group out of Seattle, Washington.

(Witness testimony continues on the next page.)

MICHAEL CARRIKER, SENIOR ENGINEERING PROJECT PILOT 737
BOEING COMMERCIAL AIRPLANE GROUP, SEATTLE,
WASHINGTON

(Whereupon,

MICHAEL CARRIKER,

was called as a witness by and on behalf of NTSB, and, after having been duly sworn, was examined and testified on his oath as follows:)

MR. SCHLEEDE: Mr. Carriker, could you give us your full name and business address for the record?

THE WITNESS: Michael Carriker, Boeing Commercial Airplane Group, Post Office Box 3707, Seattle, Washington.

MR. SCHLEEDE: What is your position with Boeing?

THE WITNESS: I'm a Senior Engineering Test Pilot, Engineering Project Pilot, assigned to the 737.

MR. SCHLEEDE: How long have you worked for Boeing?

THE WITNESS: Five years.

MR. SCHLEEDE: Could you briefly describe your education and background?

THE WITNESS: I have a B.S. in aeronautical engineering. I spent 12 years in the United States Navy, a graduate of the United States Navy Test Pilot School and an instructor at the Navy Test Pilot School and an instructor at the Empire Test Pilot School in Boscombe Down, England.

Since coming aboard for Boeing, I have type ratings in all the current production airplanes and a provisional type rating in the 777. I'm flight instructor qualified in the 737 and the triple 7.

MR. SCHLEEDE: Roughly, how much total flying time do you have?

THE WITNESS: About 4,700 hours of flight time.

MR. SCHLEEDE: Is that mostly flight tests?

THE WITNESS: About 3,000 of it.

MR. SCHLEEDE: How much, roughly, do you have in the 737?

THE WITNESS: 1,300.

MR. SCHLEEDE: Thank you very much.

Mr. Jacky will proceed.

MR. JACKY: Good morning, Mr. Carriker.

THE WITNESS: Good morning.

MR. JACKY: I want to ask you first of all in what capacity did you participate in the investigation of the accident in 427?

THE WITNESS: Initially I was assigned to the Operations Group. On the morning of the accident it became apparent that the Operations Group had enough people. They weren't going to actually go to the scene. I requested permission to join the Cockpit Voice Recorder Team, so I went to Washington, D.C. and participated in that regard.

When they came back to Seattle to start doing the simulator evaluations, my position of being on the CVR team and aware of the accident and my job as being a 737 engineering pilot, I assisted the Performance Group in the simulations.

MR. JACKY: When the FAA is performing certification flights for certain aircraft, specifically Boeing aircraft, are Boeing pilots represented in those tests?

THE WITNESS: Yes. At all times. The

sequence of events is that the Boeing Company goes out and performs the tests. And like Mr. Berven said, when we're ready to demonstrate the airplane, we get what's called from the FAA a type inspection authorization and then a Boeing pilot goes along with an FAA pilot from the Aircraft Certification Office and we demonstrate to them. It's the FAA's choice whether they want to watch or if the FAA pilot wants to fly it. That's a decision made on a case by case basis. And then the airplane's performance flying qualities are demonstrated to comply with FAR Part 25 regulations.

MR. JACKY: You mentioned the FAA's Aircraft Certification Office. Would that be the office in Seattle?

THE WITNESS: There is one in Seattle. Yes.

MR. JACKY: And would that generally be the particular group that Mr. Berven works with?

THE WITNESS: Yes.

MR. JACKY: Okay.

THE WITNESS: I hope I have all my FAA terms correct.

MR. JACKY: Did you have an opportunity to participate in the FAA -- let me back up for a minute.

In the simulator studies that were performed for the Aircraft Performance Group and also previous to that for the FAA, the studies were performed in Boeing's en-cab simulator. Is that correct?

THE WITNESS: That's correct. We have an M, that stands for multipurpose cab. Like Mr. Kerrigan a little bit yesterday, it is a generic airplane simulator. We can change the parameters very easily in the simulator. It has the exact database that goes into any simulator, but we know the individual coefficients of the aileron, the spoilers, the rudders, and we can control those variables.

So if we want to in this case simulate a fault, then we can instruct the computer to take that part out or add that part into the simulator database, the program that calculates the numbers that display in the cockpit so we can make these changes and we can make them incrementally.

We can also input those faults from the outside so the pilot doesn't have to step on the rudder peddle at 2-1/2 degrees per second. We know that it goes in and we know that it goes in at the right time and the correct rate.

MR. JACKY: And how are those inputs controlled again?

THE WITNESS: We have a computer operator. The simulator operator just types them in, changes the variables in the computer program and lets them go. And they know from their aerodynamic data how to change the variables.

MR. JACKY: There was some talk yesterday about the comparison between an engineering simulator and an airline training simulator, I believe. In your opinion, how do those compare?

THE WITNESS: From a flying quality standpoint and a handling standpoint, there is no difference. We don't need to have radio panels in there. We don't need to have a transponder panel. We're not looking at those things. We actually have a different simulator to do lighting evaluations.

The multipurpose cab is there for flying qualities analysis, systems failures analysis, things like that.

MR. JACKY: Did you happen to hear Mr. Berven's testimony?

THE WITNESS: Yes.

MR. JACKY: And were you present when the FAA performed the simulator test at the Boeing M cab?

THE WITNESS: Yes. Mr. Berven was in the left seat and I was in the right.

MR. JACKY: I don't necessarily need for you to go through each and every one of the tests that were performed in that simulator session, but could you characterize the simulated failures that were run? Well, can you characterize the simulator failures that were run?

THE WITNESS: They were the same general scenarios that we had for the first Performance Group investigation, although we couldn't put the rates in. We had to manually put these rates in. And what we were interested in looking for were, as Mr. Berven said, you know, hardover rates, the type of recoveries, what it takes to look at, what effects, you know, what is the visual scene outside the airplane, what cues did the pilot have. Also interested in where the simulator would result. You know, what results the simulator would get back out.

We found that with the data in the simulator, as Mr. Kerrigan said yesterday, when you get to these very high angles of side slip, 10, 12, 15 degrees of Beta and then you also put the airplane up to 3 and 4 G's and put it above the stall of the airplane, the simulator -- we don't know how valid our simulator model is after that point in time because we don't have any flight test data. We've never spun the airplane. We've never put in full rudder peddle and full left stick.

MR. JACKY: And how would you characterize the results of this test? We still have the sheet up from Exhibit 13-B and you mentioned that the tests that were performed in the FAA simulator session were comparable to the ones ran in the first Aircraft Performance Group session?

THE WITNESS: Yes, except that they weren't quite so controlled.

MR. JACKY: Okay.

THE WITNESS: We didn't have the specific points.

MR. JACKY: And without necessarily going through each of the test, how would you characterize the results of these tests?

THE WITNESS: I agree with -- Mr. Berven made some points that when you fly the airplane and you put in a -- put in slow rudder rates and proper recoveries, the airplane flies like you'd expect any airplane to fly. You have control power. The airplane responds to what the input is.

We saw that if you delay a reaction or if you don't put in a full and proper authority reaction to what's happening then the recovery is markedly different than if you put in full timely controls.

We tried lots of things also. We didn't have a great idea of what had happened at that point in time, what had happened in the accident, so we were trying to match scenarios. What does this do if we do this? Let's look at the results. It comes out the other side. Does that match the flight data recorder? Well, no, it doesn't. And that would help eliminate possibilities.

MR. JACKY: Is it your opinion that any one of these tests might have replicated the FDR traces at least initially of the upset?

THE WITNESS: We can't find the -- on these tests that we did for the FAA and for the first time that the Performance Group was there, none of them really replicates the whole event. That's why we went with the vortex simulation because we can't get a single failure that causes the initial oscillation between the 7 degrees and back to 30 and back in 18-19 degree range and back over.

But then we knew that some sort of yawing input was put in and it was added by a rate, a slow rate as compared to what the possibility of it is. And we found that the 2-1/2 degree and the 5 degree per second rudder input rates matched from a qualitative standpoint. From a pilot standpoint sitting in a simulator and reading the flight data recorder, they were matching each other.

But the .5 degree per second was too slow. The rudder hardover rate when it runs at 52 degrees a second exhibits -- it has to -- if it yaws very much, you'd get a very definitive heading change before the airplane rolls.

MR. JACKY: Did you participate in the simulations of the wake vortex model?

THE WITNESS: Yes, I did.

MR. JACKY: And what was your experience on the quality of Boeing's model of the wake vortices?

THE WITNESS: I thought it was very good. I've never seen a wake vortex. The five or six encounters that I've had in a 737, it matched it very well. It's what you'd expect.

We tried several different events to prove to ourselves that it worked well. We didn't always start on the left side and stick the right wingtip into the vortex. We started in the middle of the vortex, put the center of the gravity of the airplane in the middle of the vortex, and watched it have this pure rolling moment, which was indicative of what we had.

So, we could verify that the simulation was as good as any simulation we have ever had.

MR. JACKY: So qualitatively the results would be similar to what you've experienced in flying?

THE WITNESS: Yes. And I did that from -- I know that the times that I've known what the vortex was, we do a flight test technique called a wind up turn. It's to look for stability characteristics in the airplane. But in those cases you do a very rapid 360 degree turn and you cross back through your own vortex and then you get that thumb that Mr. Berven was talking about. And that's definable. You know that you're the one that caused it.

And so we did the same sort of test here and we got the same reaction. Remember that we can't really predict upon the vertical acceleration in the cab because there are hydraulic jacks and rams and there's limited authority. But the gauges displayed the same sort of vertical G bump that you'd expect to have in the airplane. Plus the motion simulator is very good and it also helped out.

MR. JACKY: Have you ever experienced a wake vortex trailing behind another aircraft?

THE WITNESS: Yes.

MR. JACKY: Could you characterize the duration of that experience?

THE WITNESS: They are in the one or two second time frame. The ones that I've had behind another airplane trail is landing behind 747's and getting rolled due to that. And it's basically that the airplane rolls rapidly, but at the same time the lift vector of the airplane has a tendency to take you right out of the vortex. So you get this rather -- you get a rapid rolling moment, but then at the same time, that rolling moment also takes the vector of the airplane and takes it out of the vortex.

So you get this rolling moment and then it's done and you're left at some 20-30 degree bank angle from which you recover from.

MR. JACKY: Are you familiar with the yaw damper system on the 737 aircraft?

THE WITNESS: I have general familiarity with it.

MR. JACKY: Is it your experience that you can feel the yaw damper actively moving during normal operation?

THE WITNESS: During normal operations, no, you can't. Sometimes you can perceive it working. In a turbulent situation you can possibly feel it working, but it's very hard to distinguish between the yaw damper working and outside turbulence.

There is a gauge in the cockpit and I can't quite make sure if it's a customer option or if it's there and it actually shows a yaw damper actuating, but it's not a normal item that you scan.

MR. JACKY: You mentioned gauges in the cockpit. Are there any gauges in the cockpit that would indicate the position of the different control surfaces on the 737?

THE WITNESS: No. There's trim position indicators for the airplane but to look at the elevator position, the rudder position and the aileron position you'd have to look at your feet and your hands.

MR. JACKY: In your experience in the 737, have you ever encountered an in-flight thrust reverser deployment?

THE WITNESS: Yes. Yes, I have.

MR. JACKY: And could you characterize what that experience would be?

THE WITNESS: The test that we did it, we did it at 250 knots at the beginning with the engine at idle and you have to bypass the safety systems and open it up.

Even though I was the one that opened up the thrust reverser, it was a -- it's very loud. There's a lot of buffeting and vibration in the airplane. It's controllable. A little bit of rudder peddle and a little bit of aileron stops the roll rate and you can fly with it.

What was interesting to me was the amount of noise and shaking in the airplane that went on when that thrust reverser opened up. And we continued down to flaps 1 and 210 knots. We got down to flaps 5 and decided to shut the engine, to close the reverser bay.

MR. JACKY: Do you know whether the thrust reverser deployed all the way?

THE WITNESS: Yes. It deployed all the way.

MR. JACKY: And did you feel any appreciable yaw moment as a result of that deployment?

THE WITNESS: Yes.

MR. JACKY: You said that you were a member of the Cockpit Voice Recorder Group. Is that correct?

THE WITNESS: That's correct.

MR. JACKY: And as a member of the cockpit voice recorder group, did you have an opportunity to listen to the CVR take from this?

THE WITNESS: Yes.

MR. JACKY: Was there any sounds or noises during the listening of the tape that would be indicative in your experience of a thrust reverser deployment?

THE WITNESS: No.

MR. JACKY: I have no further questions.

CHAIRMAN HALL: Thank you.

Any questions from the parties?

I only see a hand from Boeing.

Any other party have a question? If not, Mr. Purvis, please proceed.

MR. PURVIS: Mr. Carriker, we have a couple of questions for you.

You were just talking about the thrust reverse in-flight deployment. Would the throttle snatch system bring the engine parameters down that would be observable on the FDR?

THE WITNESS: Yes. We didn't -- in our flight test we didn't test that system. We were testing for flying qualities with the thrust reverser open, so in a controlled test, we put the throttle at idle and then opened up the thrust reversers. But the system is designed to bring the throttle back to idle if the thrust reverser opens.

MR. PURVIS: And on the accident airplane, if it came open, you would have seen it on the --

THE WITNESS: Yes.

MR. PURVIS: -- flight data recorder?

THE WITNESS: Yes. It would be been independent of the other engine.

MR. PURVIS: Thank you.

I'd like just to clarify that you flew these flight simulations that are shown on Exhibit 13-B, page 4 that's on the viewfoil machine?

THE WITNESS: That's correct.

MR. PURVIS: In the Item 2 that's called Rudder Hardover Rates, was the airplane traveling at the accident -- or at the 190 speed and 1 degree flaps?

THE WITNESS: Yes. The test conditions on all these performance tests that the Performance Group did, the test conditions were the same altitude, same airspeed, same flap configuration setting. The airplane had the same gross weight. The airplane had the same center of gravity and we had the same systems built in the airplane so that we'd know that fact.

MR. PURVIS: For the Condition A where it shows half a degree per second rudder hardover rate, was the airplane fully recoverable under those conditions?

THE WITNESS: Yes. The rate is so slow in that case that you just watch it for a few seconds and you kind of say, you know, "What's going on there?" The autopilot comes in and the autopilot counteracts it easily in the beginning and then you have time to analyze it and take it off. And then your feet, if you have your feet on the rudder peddles, your feet are moving.

MR. PURVIS: And a similar question for the 2-1/2 degree/second. Was it fully recoverable under those circumstances?

THE WITNESS: Yes.

MR. PURVIS: And for the 5 degree/second rate?

THE WITNESS: When you're talking about in the 5 and the 10 and the hardover rate, all these events are recoverable events.

MR. PURVIS: Okay.

THE WITNESS: I guess to expound upon that, the recovery, it would be as Mr. Berven said. You would see probably 90 degrees angle of bank, but as long as you put it in full opposite flight controls and you flew the airplane to the best of its ability, you would roll out. You would out and go back to wings level.

MR. PURVIS: Okay. I want to move on to the yaw damper system. On the 737-300 is the yaw damper system required for dispatch?

THE WITNESS: No. On the 200 airplane it was required for -- you couldn't fly with the autopilot on above -- 30,000 feet strikes me. But in the 737-300, -400 and -500, the yaw damper is not required for flight.

MR. PURVIS: In your experience with

encountering wake vortex, can you get more than 30 or 40 degrees of airplane roll?

THE WITNESS: Yes. It depends how you put it. In a model, we've seen that. We know from doing their student once. Boeing did a test of flying behind a 747 with a 737 in the 1970's and that airplane rolled up to about an 80 degree angle of bank in a worst case scenario. In our tests that we performed, we had to play with it quite a bit, but if you made the parameters just right, you would see in the 50 degree range of a bank angle.

And that was getting into one vortex and having it spit you back into the next and you coupled up the events. If you just started in the middle of a high vortex and turned the simulator on with the center of gravity of the airplane parked in the middle of the vortex, you would get in the 50 degree range.

MR. PURVIS: You participated in the recent test where the NTSB groups used the CVR coupled with the simulation?

THE WITNESS: That's correct.

MR. PURVIS: What was your impression of that experiment?

THE WITNESS: The impression was, one, that it brought back into focus the time that the event happened. It could have added awareness to having the cockpit voice recorder looking at an airplane that does this same scenario, the same thing the flight data recorder said it did, and it lended (sic) more emphasis to listening to the tape to try to get any noises and to see if it could capture anybody's ideas of what some of the unidentified noises were -- are.

MR. PURVIS: Based on your participation in that test, do you have any recommendations for the future, such as using it earlier or anything?

THE WITNESS: I thought it was very beneficial. I think the people that got the most out of the test were the people that were actually on the cockpit voice recorder team because we already knew to ignore some of the voice comments, the radio comments that we already knew and that we could listen to the background noises to try to pick these things out.

Of course, I think some of the folks that hadn't listened to the tape prior spent a lot of time just listening to the voices and couldn't pick up -- couldn't ignore those points.

Also, we listened to a very small part, about a minute's worth, and people couldn't recognize voices and that kind of effect. So one of the points we brought out was to maybe play four or five minutes once prior to it so you'd get the setting of the idea, the concept of what's going on in the cockpit.

MR. PURVIS: How about timing wise during the investigation, the doing of this test? Do you have any recommendations there?

THE WITNESS: It could have been done earlier. Sometimes we have -- since we have an idea that this is a benefit, it could be done earlier in the tests to eliminate a lot of questions that were floating around. You know, of what if, and does this and do that. Because like myself, I couldn't answer my own company's questions because I was sworn not to tell anybody what was on the CVR.

MR. PURVIS: Thank you.

Mr. Chairman, I have no more questions.

CHAIRMAN HALL: Thank you.

Any questions, additional questions from the parties?

The Airline Pilots? Yes, sir, Captain.

CAPTAIN LeGROW: Thank you, Mr. Chairman.

Good morning, Mr. Carriker.

You made reference to the vortex simulations that we done at Boeing. Is it my understanding from Mr. Kerrigan's testimony yesterday that those were done with the suspended vortex, both vertically and horizontally?

THE WITNESS: Suspended? I guess I don't understand suspended vertically and horizontally.

CAPTAIN LeGROW: Well, if I recall Mr. Kerrigan's testimony yesterday when the model was made for the video that was produced by Boeing, that the vortex was suspended and then the maneuver was done with a suspended vortex.

THE WITNESS: Oh, that's correct. I guess maybe I could explain a little bit better how we did this simulation. I think people had an idea how we had to break the airplane up into pieces so that we could model the flow in individual increments across the airplane because you can put your right wingtip into the flow and there's no effect on the left wingtip. So we needed to have this to break this down.

But the vortex, we could model the velocity, basically the rotational velocity of the vortex and we could start at zero in the middle and then it rises to its peak and I think we ended up at four feet. And then it decays with the inverse of the radius of the vortex after that. And they are perfect vortexes.

In our simulation, the vortexes were rapidly descending but the value of the vortex was always constant. And our visual simulation went along for about five minutes or so before we actually ran out of the visual, although the vortex would calculate -- it would calculate the vortex forever.

So we had the ability in the simulator to start the event wherever we wanted to. We could start it above the vortexes; below it; left or right; or, like I stated, directly inside the vortex. And we could find the vortex. That's one thing that we noted before. That if you don't identify the vortex in the visual then you can't find it. And it's too difficult to read a series of numbers to know where you are.

So we put the visual out there. The outside picture that you saw yesterday was an outside camera view. From inside the cockpit, we could look over and see or look up and see these two gold and purple tubes in the sky with a red bar down the middle that signified the centerline of it. And we did fly into it from any position we wanted.

We could start the simulator from any position we wanted to and then fly into it; hand fly into; let the autopilot fly into it however we wanted to get into the simulation.

CAPTAIN LeGROW: In your opinion is this something that would be representative of an actual encounter?

THE WITNESS: Yes. If you had a perfect vortex out there, yes, it would be. And, you know, you can turn one off. Actually, the more realistic one was to turn one of the vortexes off and then just run into one. And that was very representative of what you'd expect.

Normally, -- I can't ever say that I've been in a vortex where I got full left and I knew that the vortex rolled me back to the right; whereas, in this case we could watch it, very definitively watch all these motions.

CAPTAIN LeGROW: Did Boeing produce a video with a single vortex?

THE WITNESS: I don't think so.

CAPTAIN LeGROW: You testified a few minutes ago that you've encountered in actual flight vortexes. Is that correct?

THE WITNESS: Yes.

CAPTAIN LeGROW: And you described them as something of an 80 degree bank, if I recall?

THE WITNESS: No. I quoted a Boeing flight test from the early '70s where they flew a 737-200 purposely behind a 747 and rolled the airplane up.

CAPTAIN LeGROW: Do you recall at what distance that was?

THE WITNESS: No, I don't. About a minute.

CAPTAIN LeGROW: In your experience as a professional pilot have you encountered a wake vortex from a 727?

THE WITNESS: No.

CAPTAIN LeGROW: Thank you, Mr. Chairman. I have no further questions.

CHAIRMAN HALL: Thank you. Does that conclude the questions from the parties?

(No response.)

If so, Mr. Marx.

MR. MARX: During the simulation testing that was performed, were the pilots that were flying the simulator, where did they have their feet?

THE WITNESS: On the rudder peddles.

MR. MARX: During normal flight of a 737 would you be expected to have your feet on the rudder peddles?

THE WITNESS: We'd normally expect to have the pilots' feet on the floor in the front of the rudder peddles or on the rudder peddles.

MR. MARX: Is there any other position that the pilots' feet could be besides on the floor or on the rudder peddles?

THE WITNESS: Oh, sure, there is, but it would be what you would think to be a proper pilot position.

MR. MARX: I mean, is there a foot rest that they have in the cabin where you can put your foot up?

THE WITNESS: No. There's not a specific foot rest inside the airplane.

MR. MARX: It's not. But is it used as a foot rest?

THE WITNESS: Yes.

MR. MARX: Is it commonly used as a foot rest?

THE WITNESS: It wear out a lot. Yes.

(Laughter.)

MR. MARX: Well, I'm trying to get an idea if pilots normally would fly with their feet on the rudder peddles and the consensus I'm getting here is that they don't. They have their feet on the floor.

Is that different than what --

THE WITNESS: I think it has to do with the phase of flight. You could say in this phase of flight where 427 was, that the pilots would have had their feet on the floor or on the rudder peddles. It's 10,000 feet. They're ready to land. They've done all their proper briefings. It's not 35,000, three hours left to go before they start their top of descent. That's when you'd expect maybe for the pilot to have his feet not on the peddles or on the floor right in front of the peddles. But when they start the top of descent, the airplane starts coming down, the activity picks up, the requirements to fly the airplane are very apparent and you'd expect the pilot to have his feet in the location of the rudder peddles.

MR. MARX: Well, if the pilot had his feet on the floor and you had a runaway rudder, would he know it?

THE WITNESS: If you have a runaway rudder, you would have a four inch displacement, plus or minus, for the rudder peddles. There'd be an eight inch difference between the rudder peddles.

I guess if you have your -- that's a question. If your feet are right there, it would hit your ankles with the rudder peddle.

MR. MARX: It would come at hit your ankles?

THE WITNESS: Well, if your foot is within four inches, was stationed within four inches of the rudder peddles.

CHAIRMAN HALL: Mr. Clark?

MR. CLARK: Mr. Carriker, have you participated in any flight tests where an attempt was made to duplicate this accident scenario or portions of it?

THE WITNESS: I participated in a flight test where we looked to get extra data to try to verify our simulator model as to what would happen if you had a roll rate and then you added a rudder input on top of that.

MR. CLARK: Would you describe those tests?

THE WITNESS: We took a 737-300 airplane; went out -- we actually did it at 35,000 feet. We were at flaps 1, 190 knots. I rolled the airplane to 7 to 8 degrees per second rate of roll. At 45 degrees left wing down, I put in a left rudder about as the flight test data showed later, about 6 or 7 degrees of rudder, and then I let the airplane -- and then saw what the roll rate was. And passing a 60 degree angle of bank, rolling through 60 degrees angle of bank, I took out the rudder peddle and recovered the airplane.

MR. CLARK: When you were putting in the rudder peddle, what kind of aileron controls were you putting up?

THE WITNESS: I still had enough aileron to maintain that roll rate, which is about 30 degrees of aileron.

MR. CLARK: So maintained a constant wheel position and then put in the rudder, --

THE WITNESS: Yes.

MR. CLARK: -- maintaining the constant wheel position?

THE WITNESS: Yes.

CHAIRMAN HALL: When you say put in the rudder, that's putting your foot on the peddle?

THE WITNESS: Yes.

CHAIRMAN HALL: And then when you say taking it out, is that taking your foot off the peddle?

THE WITNESS: Yes. Putting it in -- yes, that's correct. Putting it in means I put a rudder input in and I tried to put it in at a specific rate and I tried to go to a specific end value and then hold it there for a time period just so we could get the data and see what it looked like. And then took it back out.

I didn't step on the opposite rudder. I allowed the rudders to go back to neutral and then I rolled the airplane back to wings level and then pulled the nose up.

CHAIRMAN HALL: Sorry, John.

MR. CLARK: That's all right.

As you were rolling the airplane into this test, what kind of G rate were you commanding?

THE WITNESS: One.

MR. CLARK: And what kind of speed excursions did you experience?

THE WITNESS: Once the airplane rolled, since I didn't purposely keep the nose up, the airspeed built up. So during the maneuver, actually retracted the flaps from 1 to up because there's 230 knot restriction on the airplane. At no point in time during the flight test did I exceed any of the airplane flight manual limitations. But we ended up at 230-235 knots.

We also ended up at about 90 degrees left wing down and 30 degrees nose low.

MR. CLARK: And 30 degrees on the pitch?

THE WITNESS: Yes. We also performed steady heading slide slips, and --

MR. CLARK: Let me go back for just a second. How much altitude did you lose in those maneuvers?

THE WITNESS: Since I was limited two G's, maximum of two G's on the recovery and I didn't want normal roll rates, I lost about 2,500 feet.

MR. CLARK: How many of these types of tests did you perform?

THE WITNESS: We did one series of them; seven to 10.

MR. CLARK: And you have the FDR data on all of that?

THE WITNESS: Yes.

CHAIRMAN HALL: Were these tests performed as part of the party work or were these tests independently performed by Boeing?

THE WITNESS: The tests were performed by Boeing under an engineering work authorization to try to help verify the simulator database that we were using for the M-cab for the performance group to use.

MR. CLARK: Okay. You were going to describe a steady heading side slip?

THE WITNESS: Oh, we also did -- on those tests, not only did we just look at the roll rates. We looked at steady heading side slips, so we had -- like I said, there was a 737-300 airplane and we went to flaps 1 and 190, and again looked at steady heading side slips, the ability to stop the roll and the controllability of airplane, and found out that it matched fairly well in the simulator at 190 knots.

It takes about 70 percent of the wheel authority once you get stabilized and then if you control the airplane in pitch to slow the airplane down, at about 170 knots it's a tie where the aileron and the rudders match. And then at 210 knots or so, it's about 40 to 50 percent of the wheel to counteract the full rudder.

MR. CLARK: Were any of those tests conducted in a dynamic manner?

THE WITNESS: No.

MR. CLARK: You answered Mr. Purvis' questions on the rudder rate tests that were conducted in the simulator, in which I believe you stated that for all the rudder rates, all of these events were recoverable.

I guess my question is are you aware of any dynamic type testing that's being done to validate the simulator in that flight regime out to those extremes?

CHAIRMAN HALL: John, could one of you all explain what you mean by a dynamic test?

THE WITNESS: You want me -- dynamic testing, when they do the -- the classic stability control says you'll go out and do a steady heading side slip, as Mr. Berven explained. When you do a steady heading side slip you're looking for a couple of different factors: One, you're trying to prove that the airplane has positive directional stability, i.e., the nose of the airplane always wants to go into the wind. And it's linear, so you can test that by stepping on the rudder peddle input and that causes a rolling moment and that rolling moment is counteracted by the ailerons.

It also causes a side force moment because you actually have wind blowing against the side of the fuselage, and that's counteracted by the bank angle.

So, you can check the linearity. You can check the values of how the airplane flies by constantly increasing these parameters and checking to make sure that you have to constantly increase the aileron, the lateral flight control against it, and that your bank angle constantly increases.

And when you go to the limit of the control authority and you can check these lines and they don't reverse, it doesn't take less bank angle at a higher rudder, that the rudder doesn't have a tendency to go to an uncommanded position in these flight tests. And that's a static stability case.

A dynamic stability case is where you literally just go up and stomp on the rudder peddle. In that case the inertia terms of the airplane have a big effect. Get this mass of metal moving quickly, it has a tendency to overshoot its final commanded position and then it comes back to that commanded position. And at the same time you set up oscillatory modes that are present in airplanes such as the Dutch roll mode.

So, if I had just stepped on the left rudder peddle hard, the airplane would have a tendency -- it would yaw and then it would roll. Some of that yaw angle would actually come back out and then go back in and come back out and go back in. And that would be the Dutch roll mode.

In the 737, even with the yaw damper not installed, that oscillatory mode always stops. It may take quite a few cycles for it to stop, but it always does dampen out. But it's a more dynamic test.

One of the most dynamic tests that you do is engine failure. You can either have an engine failure shut down and just slow down and look at it, or you can just be at the speed that you want to test it for and then just shut it off.

CHAIRMAN HALL: Thank you.

MR. CLARK: If we don't have the dynamic data to validate the simulator, it is possible that the simulator may be recoverable under these hard rudder inputs, wherein out in the actual world, the airplane won't operate?

THE WITNESS: That's a question we don't know. The simulator data we have, as Mr. Kerrigan explained yesterday, is derived from flight test data. We don't have flight test data where you have full rudder peddle inputs in a stalled condition. We just have to use the best wind tunnel data that you have and model that.

MR. CLARK: You've flown flight tests in which the airplane is rolling and you put in -- you rolled to the left and put in left rudder and you participated in that simulator work and that backdrive model work where you see the visual cues.

In any of your experience in this area have you seen any visual cues or felt any motion cues that would tend to make you put in left rudder peddle as that situation started to develop?

THE WITNESS: No.

MR. CLARK: From your experience in the simulation work and your wake turbulence encounters, would you expect a 737 to be upset by the wake of a 727 at four miles?

THE WITNESS: In the cases that we had there with the clear turbulence and what I know of vortexes and if you were flying up, you kind of flew up into it, yes. I'd expect it to roll the airplane in the 20 degree bank range.

MR. CLARK: And one point I believe -- and correct me if I'm wrong. You said that in some of the turbulence encounters you saw up to 50 degrees bank angle. And in that, would you describe the wheel responses or the pilot corrective action? Were they delayed or where they --

THE WITNESS: No. These were -- none whatsoever.

MR. CLARK: So you were seeing 50 degrees without any response from the pilot?

THE WITNESS: That's correct.

MR. CLARK: And so that number would be less if a pilot took timely action?

THE WITNESS: Yes.

MR. CLARK: And in one case I believe it was answered, but in the case where you have seen data up to 80 seconds, that was strictly behind the 747 and whatever, a time delay of 60 seconds?

THE WITNESS: Yes.

MR. CLARK: That was not --

THE WITNESS: That was a specific test looking for wake. I mean, they purposely flew the airplane into the event. Eighty degrees may be a bit high. It's a very dramatic videotape to watch.

MR. CLARK: Okay. But in that situation, that's not consistent with the scenario that we believe is going on?

THE WITNESS: No. It's a much higher wing lowering airplane. It has a lot higher vortex capability, a lot closer, and also disperses into the ground, which the effects breaks it up, does different things.

MR. CLARK: Okay. Thank you.

I have no further questions.

CHAIRMAN HALL: Mr. Schleede?

MR. SCHLEEDE: Yes. Regarding the testimony about these flight tests where you were matching the circumstances of flight 427, when was that done, the time frame?

THE WITNESS: The simulator studies, or --

MR. SCHLEEDE: No. The ones you were doing in the airplane.

THE WITNESS: The first part of October.

MR. SCHLEEDE: Is that test plan or the rests of that, is that in our record? Is it in the record for the hearing?

THE WITNESS: I don't know. I'd have to ask our Group Chairman that. I haven't read all the inputs that Boeing has.

MR. SCHLEEDE: Was the data reduced and plotted from these flights?

THE WITNESS: Yes.

MR. SCHLEEDE: Thank you.

That's all I have.

CHAIRMAN HALL: No questions, Mr. Laynor?

(No response.)

Just one or two questions, Mr. Carriker.

John, Mr. Purvis, you have a comment?

MR. PURVIS: May I put another question to him?

MR. PURVIS: You're not timely, but yes, you may.

MR. PURVIS: Sorry.

Mr. Carriker, have you flown the 737-300 with the yaw damper at a hardover condition, say the full three degree authority? And if so, what's your experience?

THE WITNESS: Yes. You can simulate a yaw damper hardover. You don't have to inject the fault. You can just trim the airplane -- trim the rudder to three degrees over, keep the rudder squared away with your feet, and then take your feet off. That simulates a yaw damper hardover.

The airplane oscillates left and right as the Dutch roll dampens out. Turn the yaw damper off so it doesn't work, and then put this in. And then the autopilot handles it within 15 to 20 degrees of bank and it stops.

It depends on the flight condition. If you do it at very high speeds it's more dramatic. If you do it at very low speeds it's not very much.

MR. PURVIS: Would you characterize it as controllable?

THE WITNESS: Oh, yes, by the autopilot. If you don't do anything, the autopilot will cancel it right out.

MR. PURVIS: Okay. Thank you.

CHAIRMAN HALL: Mr. Carriker and representatives of Boeing -- gentlemen, if those results of that test are not presently part of the record, I would appreciate it if they could be submitted since they were discussed at this hearing, and could be made a part of the public record.

Mr. Carriker, you mentioned that you were one of the individuals that participated in the simulation where we used a portion of the cockpit voice recorder tape in the simulator. And were you able to learn anything else in addition concerning the accident flight after that simulation with the cockpit voice recorder than before?

THE WITNESS: No. As a group of 16 people that sat through simulations, we didn't identify any extra noises. Myself, as being a member of the CVR team, I had another chance to listen in and try to associate some of the noises with what I thought was going on in the airplane. But no, there was no identification of any of the thumps that resulted from this test.

CHAIRMAN HALL: So we still don't have a clear idea or know -- well, we weren't able to identify some of the sounds that are on the tape?

THE WITNESS: No. We had lots of ideas but everybody had ideas of what it could be but nobody said, "I know that it's this."

CHAIRMAN HALL: My experience in traveling around is there's a lot of use now in terms of trip or traveling purposes, of video cameras in cockpits. Does Boeing use that routinely with your simulators?

THE WITNESS: Not in the simulators. Actually, in flight tests we put video cameras in the cockpit. We do it to record the displays. We still have digital data taken for flight control positions for such things as that. But we use video cameras for all the displays in the cockpit now that we have -- through our ICAST systems where you get messages written up and they don't have any noise or anything like that. Then we record those kind of things on a video. We constantly record it on a video camera.

CHAIRMAN HALL: How costly do you think -- I guess you're a unique person in that you are both the pilot that's flown it and you also help program the simulator.

THE WITNESS: No. I don't help program the simulator.

CHAIRMAN HALL: You don't program the simulator?

THE WITNESS: No.

CHAIRMAN HALL: How does that -- how do you get that information then? You mentioned your flight test and they use that to program the simulator?

THE WITNESS: The stability and control people, they know the coefficients that cause the airplane -- the coefficient -- the power, how much power the aileron has, how much power the rudder has, things like this, and the results of it. So when you go out and you put in a known input in and then you get the known output, they can go back to the simulator, put that same input in and then run it through the computer and see that the answer that's kicked out by the computer matches the answer that was kicked out on the flight test.

And if it doesn't, then they go back in and make it come up with the same solution by various modifications. Make sure that what the inputs that we put in the simulator match what flight test said come out when we did the exact same thing in the airplane.

CHAIRMAN HALL: How much time have you spent on this accident?

THE WITNESS: Hundreds of hours.

CHAIRMAN HALL: Mr. Carriker, -- are there any other questions for this witness?

Mr. Clark has one more question.

MR. CLARK: I believe there's going to be some discussion later on hydraulic systems, but to your knowledge are Boeing pilots or 737 pilots trained to disable the hydraulic system in response to flight control malfunction failures?

THE WITNESS: Yes. All the time that you shut off the flight controls or to turn off the hydraulic system, it's called for in the checklist. So, I mean, we don't -- we do in our production checks but that's for different reasons. But on a normal line flight, any time that you shut off the flight control system -- and we do have the ability to shut off the two flight control systems with a switch in the cockpit -- you only do it when it's called for by the checklist because you've had a failure.

MR. CLARK: But typically in that response that's a checklist item, or --

THE WITNESS: That's correct.

MR. CLARK: -- an emergency response item?

THE WITNESS: That's correct.

MR. CLARK: Thank you.

CHAIRMAN HALL: Mr. Carriker, thank you very much for your time and you are excused at this point.

(Witness excused.)

CHAIRMAN HALL: The time that the Chairman sees on his watch is 11:55 and I would assume that would be an appropriate time for this hearing to take a lunch break and to reconvene at 1:00 p.m. sharp.

(Whereupon, the luncheon recess was taken at 11:55 a.m.)

AFTERNOON SESSION

[Time noted: 1:00 p.m.]

CHAIRMAN HALL: Call our hearing back to order and ask for Mr. Harry Dellicker to please come forward.

He is a Flight Data Recorder Data Analysis/Simulation Expert with the Boeing Commercial Airplane Group out of Seattle, Washington.

(Witness testimony continues on the next page.)

HARRY DELLICKER, FDR DATA ANALYSIS/SIMULATION EXPERT,
BOEING COMMERCIAL AIRPLANE GROUP, SEATTLE,
WASHINGTON

(Whereupon,

HARRY DELLICKER,

was called as a witness by and on behalf of NTSB, and, after having been duly sworn, was examined and testified on his oath as follows:

CHAIRMAN HALL: Mr. Dellicker, welcome.

Mr. Schleede will begin the questioning.

MR. SCHLEEDE: Please give us your full name and business address for the record?

THE WITNESS: It's Harry Dellicker, and I work with Boeing Company, P.O. Box 3707, Seattle, Washington.

MR. SCHLEEDE: What is your position with Boeing?

THE WITNESS: I'm an engineer in the Aerodynamics Group, Renton Aerodynamics.

MR. SCHLEEDE: Could you give us a brief description of your background and education?

CHAIRMAN HALL: We've begun the hearing and if you have to have conversations, please conduct them outside. We need to have the room quiet so that those that want to listen will have the opportunity to do so.

Thank you.

MR. SCHLEEDE: Go ahead.

THE WITNESS: I've been with the company for 17 years and I have worked for 12 years developing tools and methodologies for analyzing flight test data.

MR. SCHLEEDE: Do you hold any FAA ratings or certificates?

THE WITNESS: No.

MR. SCHLEEDE: Thank you. Mr. Jacky will proceed.

MR. JACKY: Thank you.

Good afternoon, Mr. Dellicker.

Could you please describe for us your participation in the investigation of USAir 427?

THE WITNESS: Certainly. I got involved shortly after the accident. Because of my expertise in dealing with flight test data, it was felt that we might be able to add some additional information in terms of understanding the airplane's motion.

Normally we work with flight test data and use these tools to compare data channels against one another to check for accuracy and to basically fill in missing pieces.

MR. JACKY: And what types of tools are you referring to in your study of flight test data?

THE WITNESS: This is what we would refer to as a kinematic analysis and the study of kinematics is a branch of dynamics that deals with aspects of motion, acceleration rate, position of a vehicle body of any type without regard to force or mass. So it doesn't matter what is acting on the body. You can use the equations of motion to use to relate one aspect of motion to another.

MR. JACKY: Can you give us a simple example of what kinematics or the study of kinematics might produce?

THE WITNESS: Yes. A good example would be a vehicle, an automobile traveling straight down the road along a straight line. Given a history recording of the speed of that vehicle as it's accelerating or decelerating, I can tell you how far the vehicle has traveled in any given period of time. I can also generate for you a history of the acceleration or deceleration of that vehicle. Again, starting only with the knowledge of the speed.

So you can fill in these two missing pieces and then, taking that a step further, assuming that the vehicle is traveling on a level road, if I know the mass or weight of the vehicle, I can give you a good estimate of the force that was acting on it to produce the calculated accelerations.

And that's a -- I should say that's a simple one degree of freedom program. Again, you're just traveling along a straight line down the road. In the case of an aircraft, we have six degrees of freedom, and that's basically velocity along the X axis parallel to the body, the fuselage, and also a roll about that X axis where the wings dip to one side or the other.

You also have velocity along the Y axis which goes out to the wings. That's the sideways motion and a pitch about that axis. And then velocity in the vertical direction along the Z axis and a yaw about that axis.

And the equations are much more complex that relate all of those together than in the one degree of freedom case, but the basic principle is the same.

MR. JACKY: Earlier, Mr. Kerrigan testified as to a backdrive simulation, a match of the flight data recorder information from USAir 427. Could you describe for us what the differences are between the backdrive simulation and the kinematic study which you performed?

THE WITNESS: Sure. Basically, using the simulation and doing a backdrive, you're trying to solve simultaneously for two sets of unknowns, both the unknown aspects of the airplane motion and for the forces that produce that motion.

Now, this is done basically by iteratively trying to predict forces acting on the airplane. You run the simulation through this match of the accident scenario and try to match the known aspects of the airplane motion that were recorded on the flight data recorder. And generally this is done with what we call a math pilot. So the real trial and error, if you will, is in developing the control laws and the gains in that math pilot that allow the simulation to match the airplane motion.

What makes it challenging is that the forces that you're trying to estimate and the unknown aircraft motion that you're trying to determine out of this are mutually dependent on one another. One will change the other. And you can get there with a simulation. Actually, the simulation is an excellent tool and we use it all the time. But in some cases it can take quite a while to get to the desired target.

In the case of the kinematic analysis, we uncouple the problem, so to speak. We break it down into two major parts. In the first case, we're solving for the aircraft motion, again, without regard to the forces that were acting on it. In this case we're starting with -- from USAir 427 we have seven motion variables. We have the three oiler angles, pitch, yaw or heading and roll, and we have the acceleration along the X axis of the body in this direction, acceleration vertically, the airplane speed and the airplane altitude.

And using the kinematic equations of motion we can work with that data and estimate the major unknowns, those being the angle of attack of the aircraft, which is the angle between the body axis of the aircraft and the air. So if he's flying along downward, we're talking about this angle here. The other angle being the side slip, which you could think of as you're driving on an ice road, you go into a corner and you turn left. The car starts sliding right and that's positive side slope. So it basically kind of skid into the turn.

That process in this case is a special adaptation of what we normally do in flight tests. Normally in flight tests we had some direct indications of the size of the angle. We have lateral acceleration, acceleration sideways. And in fact, we normally record a pressure differential across the nose of the aircraft that we can relate directly to the side slope.

In this case, the side slope actually becomes the major unknown and really the one variable that we have to deal with in this analysis. And the process is iterative.

We started out assuming, because we had no better information, we assumed that the side slip was zero. And the first time through -- let's put the chart --

MR. JACKY: You're referring to Exhibit 13-G, I believe?

THE WITNESS: Yes. Exhibit 13-G, page 17. It's also Figure A-1. It's about a third of the way through Exhibit 13.

VOICE: What page number?

THE WITNESS: Through page 17.

Thank you.

Now, this is a rather busy plot. What this shows is the effect of the assumed side slip angle on our predicted speed and angle of attack. I'm sorry. Not angle of attack but altitude. Angle of attack is not shown.

Basically, the analysis proceeds starting with a zero side slip angle and when we went through it, it produced speeds and altitudes that were greatly in disagreement with the flight data recorder. Speed at impact was about 100 knots higher than recorded and impact in fact occurs about four seconds before it actually happened, according to the FDR.

So, went into a process here. I can iteratively -- basically, make a guess on side slip using the simulator as a guide and honing in on the side slip angle that would give us a good match on these parameters, as well as the angle of attack, which I don't show here. But that match is based on the predicted stall warning with the final, what I'm calling side slip, which is this second curve from the top, we matched the stall warning onset within about a half a second. We're matching the speeds all the way through within about 10 knots following the upset, and we match the altitude very, very closely here, showing impact just after 160 seconds.

The real reason for this particular curve or the plot was to show the sensitivity of these various parameters to the side slip, just as an indication of how powerful these measurements were as a guide in arriving at the estimate that we have.

MR. JACKY: And so if I follow you correctly, you are making an estimation of the side slip angle of the aircraft over time and then using that information to backdrive the simulator to see if the altitude, airspeed and angle of attack data match the other FDR parameters?

THE WITNESS: Well, we also did that step taking this information and backdriving the simulator as a second check. But my work primarily was independent in the early stages and we were just comparing these results directly with the flight data recorder, what information we had.

Having then defined the airplane motion as best we could, we proceed into the second stage where we solve for the forces and moments acting on the aircraft using the assumed weight and inertias through estimates provided by the NTSB.

Actually, let me back up. I intended to show the match that we arrived at on airspeed and altitude. Let's go to page 20.

The three curves on this plot, the solid line represents the raw flight data recorder data, adjusted going for barometric pressure, so this is as the pilot would have seen it on his instrument.

The short dashed line represents that data corrected with a nominal position air correction that we have, that we've developed from flight tests, which accounts for the effects of angle of attack and side slope on the airspeed instrumentation.

And the long dashed line represents the final kinematic analysis which is a little bit on the low side, but the impact is at the right point in time, as far as we can tell.

The remaining difference between those bottom two curves is probably due to some remaining uncertainty in just what the position air correction would be, because we don't have flight test data all the way out into that regime of angle attack and side slope. It's an extrapolation of our data.

And on page 21, this is similar to the altitude comparison. The solid line is the raw flight data recorder information. The short dashed line is that data corrected with out nominal position air corrections and the long dashed line is the kinematically derived airspeed which is within 10 knots

-- normally closer.

During the initial phase prior to the upset, the match is essentially exact. It says within a knot everywhere. Which also indicates the low magnitude of the winds, by the way.

MR. JACKY: How far back did you go back in the data prior to the upset in order to match the data?

THE WITNESS: I started the match all the way from time zero to the full 132 seconds up to the upset and then from there on. The initial part of the data is used in helping to calibrate the acceleration data. And then once that's calibrated, you use that through the remainder of the upset to define the airplane motion.

That basically completes the kinematic part of the analysis. From there we move into the coefficient, the force analysis, where we're trying to estimate the forces and moments acting on the aircraft.

MR. JACKY: And how would you accomplish that?

THE WITNESS: That's done as in the earlier example of the automobile. You use the aircraft weight and inertia information and then the X, Y and Z directions. The forces associated with those are determined from the simple equation: force equals mass times acceleration. The accelerates we've determined. The mass we have from data. The force is a direct calculation. And similar calculations for the moments which cause the yaw, pitch and roll.

That represents the total forces and moments acting on the airplane. At the same time, we can basically predict from the simulator model the total forces and moments that we would achieve at those flight conditions. At each point in time the airplane is at a certain angle of attack. The side slope, we're assuming failed controls because we don't have that data. So we add up basically all the parts of the simulation model that we know and that gives us a total for the simulator model.

We then take the difference between that set of forces and moments versus what we calculated for the airplane and that represents a set of force and moment increments that we need to add to the simulation to make it match the estimated aircraft motion.

We can then relate those incremental forces and moments to things such as -- well, I'll back up. Those represent the combined effects of all the unknown external forces acting on the aircraft; things such as forces due to deflected controls, forces due to the wake encounter, unknown winds aloft, possible structural damage, if there were any. And it also reflects any errors that may still remain in the estimate of the aircraft motion.

A kinematic analysis is certainly not perfect, but it's very close.

MR. JACKY: So in other words, you have the amount of force difference that you have no way to account for and need to account for? Is that a correct way of saying that?

THE WITNESS: I'm sorry. Repeat that?

MR. JACKY: Well, you say you end up with an incremental amount of forces, I would assume, in each axis that you now would in some way need to account for?

THE WITNESS: Right. Yes.

MR. JACKY: And how would you go about doing that?

THE WITNESS: Why don't we start by going back to page 6. Let's start out by showing the actual raw aerodynamic coefficient data that was derived from the analysis. And what we have here on the first curve is actually the side slip angle and the second curve down is the total unknown yawing moment, the combined effects of the wake, possible rudder and anything else that may have been happening to the airplane that produce the yawing moment.

And the bottom curve is the rolling moment with similar explanation, again, due to wake activity, wheel possibly.

MR. JACKY: So this is the amount of moment coefficient that you're left over with?

THE WITNESS: That's right. After we've accounted for the side slip and everything that we know, this is what's left over. So this represents, again, the effects of the wake and controls and anything else that's not known.

MR. JACKY: And then the side slip angle at the top of the page would represent your best guess of what the estimated side slip would be?

THE WITNESS: Yes. That is right. And it showed on that little plot, if you change that side slip very much you get some serious disagreements between this analysis and the recorded data. Every 25 percent change in side slop produces about a 25 knot error in airspeed and about a 400 foot error in altitude. So we believe this is fairly close.

The next step would be to take these data and convert those to equivalent control positions or trim-out yawing moment with rudder and rolling moment with wheel. And this is done in such a way that when we put in the rudder to compensate for the yawing moment, that rudder also produces a roll and other coefficients which are fed back into the analysis. And then that would affect the wheel to trim.

Likewise, when you put in wheel to trim in the rolling moment, that affects the rudder.

If you look at page 8, this is basically the same as the previous plot except, as I say, we've converted the yawing moment to equivalent rudder and rolling moment to wheel. And in addition, we've shown the predicted blowdown angle for the rudder for comparison purposes.

In this case, we show a fairly close correlation in the levels between the predicted rudder and the blowdown angle up to the point where the airplane rolled over. Beyond that point, this would suggest that more rudder is required than what can be produced when you get beyond the blowdown angle.

The rolling moment in this case has been converted, as I say, into wheel. And it's trimmed throughout the entire time history, which means it's done as if it had actually been flown this way. So at the point where it rolls over, it would assume that the pilot put in wheel to do that, which is probably not realistic.

If you go to page 11, the difference in this plot is that we assumed that from 145 seconds on, the wheel was maintained at its maximum positive effective position of plus 85 degrees.

MR. JACKY: Which direction would that wheel input be?

THE WITNESS: Pardon me?

MR. JACKY: Which direction is positive wheel?

THE WITNESS: That's right wing down, so countering the roll. So it assumes that the wheel is maintained in that direction. And the difference in the yawing moment that that produces in the lateral control is then reflected into the rudder. As you can see, it brings down the predicted effective rudder, equivalent rudder, to be fairly close to the predicted blowdown.

What is still missing in this analysis and something that we need to do as a follow up is to determine what is happening here in terms of both the rolling moment and yawing moment. If in fact the wheel that I showed, the effective wheel that I show here represents the wheel as it actually was input, then there's a substantial negative rolling moment that's now unaccounted for, the rolling moment that actually rolled the airplane over in spite of having in positive wheel.

And corresponding to that would be very likely a fairly strong yawing moment, if this is due to some sort of stall condition of the wing which has occurred because of the increasing angle of attack. It goes through stickshaker at the point where the airplane rolls over and by my analysis it continues up into about the 24-25 degree angle of attack range. In that region, we may be getting some type of asymmetric wing stall and we have not predicted the yawing moment associated with that.

MR. JACKY: Do you have angle of attack plotted here now?

THE WITNESS: Yes. If we go to -- probably page 2. I don't have that page. Oh, yes, I do. Hold on.

(Pause.)

Sorry. Page 5. Yes. Thank you.

Angle of attack is the second curve from the top. Just below that is the indication of stall warning, which -- that's my predicted stall warning which is going off at 144.5 seconds. And as I say, the wing angle of attack continues on up into the -- oscillates between about 20 and 26 degrees.

MR. JACKY: You mentioned stickshaker. Have you tried correlating the moment of stickshaker onset by your analysis to the timing that was shown on the CVR?

THE WITNESS: According to the current analysis of the CVR, this stickshaker is sounding roughly a half a second before it did on the tape. If I take the difference in time between when the engines started to spool up -- to accelerate, and the stickshaker sounded, if I apply that to the FDR data, because we have the N-1, engine RMP in the FDR data, then that would place the stickshaker event much closer to what I have here, within about two-tenths of a second.

In fact, the original time given by the NTSB was 144.7 seconds for the stickshaker and that's pretty close, just based on that incremental approach.

MR. JACKY: If I could refer you back to page Number 6 of Exhibit 13-G.

THE WITNESS: Okay.

MR. JACKY: In looking at the calculated yawing moment coefficient increment, do you know of any control surface or any other part of the airplane that might give you that type of yawing moment?

THE WITNESS: At this point, no. We have done some testing in the wind tunnel, as you're aware, of the modeling slat damage of the number 1 slat. Actually, I have not looked at the results of that. I don't believe that it produces that much, but I'm not certain of that.

We're talking a very substantial yawing moment.

MR. JACKY: So unless there is some sort of failure mode identified on the airplane, the best fit of that increment would be served by a rudder input?

THE WITNESS: That's how we've chosen to show it. It certainly looks consistent with that. We do need to look further. We have not closed out the issue of the slat and I think that still has to be open to consideration.

MR. JACKY: Now, if I can turn your attention to page 11 of your --

CHAIRMAN HALL: Let me just clarify if I could for my own understanding here. This one yawing moment, you don't feel like you still have the answer for? You're still going to continue to do research and additions for it?

THE WITNESS: I intend to continue looking at this. There's -- especially in the initial onset of this upset, there is the question of the wake and we are working on trying to improve our modeling of that to determine how much of the roll and yawing moment may be due to the wake and see what's left over that can be attributed to the controls or whatever else was involved.

CHAIRMAN HALL: How long has it taken you up to this point? When did you start this work?

THE WITNESS: I started this September 23rd. I've put probably between 600-700 hours into this so far.

CHAIRMAN HALL: Thank you.

I'm sorry, Tom. Go ahead.

MR. JACKY: Thank you, Mr. Chairman.

The equivalent rudder angle that we show on the chart on page number 11, to me the line shows a certain amount of -- excuse me -- a jaggedness, or it doesn't seem to be a smooth line. Would you expect it to be smoother?

THE WITNESS: We're talking about the equivalent rudder now?

MR. JACKY: The equivalent rudder. Yes.

THE WITNESS: Yes. Most of that noise is related to the -- most likely the sample rate of the data, which in general is quite low. The maximum sample rate that we have available is the vertical acceleration and that was a sample. The second other parameters which more directly affect this, such as heading angle, are only one sample a second. And that tends to produce a lot of artificial noise in the data.

I could have filtered that out. I chose to leave it in here for the time being, just show it as it is. But that's something we could work on.

MR. JACKY: And just for comparison sake, when you're working with flight test data, what sort of sampling rates are you looking at to deal with there?

THE WITNESS: Typically, we work with 20 samples a second or more. Twenty is generally considered the minimum, although there are some parameters where you can get by with less, but that's our normal.

MR. JACKY: And if I can refer you to the equivalent rudder angle again, at approximately time 1:35 there seems to be a spike in the rudder position to about 10 degrees and then it comes back down.

THE WITNESS: Right.

MR. JACKY: Do you have any feel for what may be causing that?

THE WITNESS: Our best guess right now, and it's still a guess, is that that's wake induced. There is a spike in the rolling moment, the yawing moment, lift, drag, and even a little bit in the pitch that all occur right at that point in time. And that is, like I say, it's most likely related to the wake.

If this were actually a rudder event producing that spike I would not expect to see the related motion in the other data channels. You wouldn't get a big spike in lift and drag and what have you, because those are all accounted for pretty well in the simulator model.

So if you put the rudder in, we would compute the lift and drag associated with that and you shouldn't see this showing up. So it's most likely a wake phenomena.

MR. JACKY: So if I could perhaps summarize what your conclusions of the kinematic study is that by estimating the side slip angle shown at the top of the chart, you then end up with the equivalent rudder and wheel angles or positions that are shown on the bottom of the chart?

THE WITNESS: Yes. That's right. And those angles, both the rudder and the wheel, are fairly strong functions of that side slip angle. And if something were to change the estimate of side slip, that would result in changes also in the rudder and wheel.

MR. JACKY: And how confident are you in this data?

THE WITNESS: I'm pretty confident based on the overall match against the FDR data. Like I say, we're matching the airspeed and the altitude and stickshaker onset point. We also know that the stickshaker, according to the CVR analysis, the stickshaker remained active from the time that it tripped all the way to impact. And that's pretty well borne out by this analysis. At the very end mine goes intermittent, but that's like the last three-tenths of a second.

So up to that point, everything looks pretty good.

MR. JACKY: And as your work progresses from this point, what type of things would help you in further refining this dataset?

THE WITNESS: Well, certainly lateral acceleration would be very helpful if we had an adequate sample rate. That would give us a much greater degree of confidence in our calculation of Beta -- the side slip angle. I'm sorry.

Beyond that, of course, it would be real nice to have rudder angle and remove a lot of guesswork.

MR. JACKY: That leads me into my next question. If there were certain parameters or something that could be recorded on the flight data recorder that would help you in your efforts, what type of things might you wish to see or would help you directly with this effort?

THE WITNESS: Well, in addition to the lateral acceleration, -- and preferably I'd like to have everything in a little bit higher sample rate -- to really answer questions like this I think you'd need to have surface positions, pilot control positions. Ideally, even the forces, peddle forces, wheel forces and what have you, so that you could really nail down whether it was pilot input or otherwise.

MR. JACKY: And if there were some sort of video recording in the cockpit, is there any sort -- or can you imagine any sort of information coming from that that might help you in this effort?

THE WITNESS: If the camera were properly placed so you could really see what was going on, yes, I'm sure it would have added information in this case. For the kinds of analyses that I do, I'd much rather have the digital data on the FDR and if I had all of those items instrumented and recorded.

MR. JACKY: So if anything, it might give you some verification as to wheel position say, or --

THE WITNESS: Yes.

CHAIRMAN HALL: And just in layman's terms, there are things that you could put in this simulator, parameters, that if you had that information off the flight data recorder, it would help you in your work? In other words, that simulator and your calculations, you could have used additional information?

THE WITNESS: As I already mentioned, if we had the lateral acceleration, for instance, I could calculate the side slip angle with a much higher degree of confidence and although that still wouldn't tell us what produced the related yawing moments and rolling moments, at least we would be quite confident in our levels of those.

I feel from the overall match that we have a good estimate, but it's still an estimate.

MR. JACKY: Thank you, Mr. Dellicker. I have no further questions.

CHAIRMAN HALL: Could I see the hands of any of the parties that have questions for this witness?

I see Boeing. Anyone else?

If not, Boeing Group.

MR. McGREW: Mr. Dellicker, just a couple of questions.

How would you relate the quality and the accuracy of this analysis versus those reconstructions that Boeing has carried out in past years?

THE WITNESS: I believe that this is much higher quality, largely owing to the higher quality data available from the airplane and the additional data. This is I think the first time we've had this many parameters available. Well, maybe not the first time. The first time I've been involved, anyway, and we've had this many parameters available to us.

In other accidents where we're dealing with the directional gyros and such, once you get upset past a certain pitch angle and roll angle, you can't rely on the heading angle from those instruments, and that would make this analysis very difficult.

MR. McGREW: One other question. In the event that a video recording were available from the cockpit, would not the instruments or the readings of the instruments as the event progressed be of great benefit?

THE WITNESS: I'm trying to think what additional information would be available there that we don't have recorded. Certainly what's going on with the pilot controls, if anything, would be very beneficial. We have airspeed, altitude, all those recorded on the FDR.

MR. McGREW: Thank you.

I have no further questions, Mr. Chairman.

CHAIRMAN HALL: All right.

Any other parties have any questions?

(No response.)

If not, Mr. Marx.

MR. MARX: I just have a quick questions.

I'm getting very confused about the degree of rudder change that occurs and the speed of its change. In the last example where you were talking about -- and this would be Exhibit 13-G, page number 8. And you talk about equivalent rudder angle. As it goes from its first spike of the rudder input and after that, that happens at the end of the spike is somewhere around 130 -- what I calculated, about 136-1/2 seconds.

And then as you go towards at about 139 seconds, you have it reaching a blowdown angle. That's roughly 2 to 2-1/2 seconds, and yet it's going about in the neighborhood of 15 degrees. Is that correct? So it's about 7 to 7-1/2 degrees per second?

THE WITNESS: Ah, --

MR. McGREW: Or am I just confused or I have the wrong math there?

THE WITNESS: I think that's -- well, let's see.

(Pause.)

Yes. It could be that high. We had previously estimated up to 6. Another thing I should mention here is that the side slip angle at the top of that page is actually a little bit -- maybe a little too idealized. There is in fact some Dutch roll motion that I know was taking place between 135 and about 141 seconds.

And the effect of that, if I were to go back into this analysis and account for that, would be to soften that slope with the rudder a little bit. In other words, right at about 136 seconds, the equivalent rudder would go up and at 139 it would go down a little bit so it would tend it round it off. And I haven't had a chance to go back and rerun the analysis with that.

MR. MARX: Well, the information we have from Mr. Kerrigan, I guess it was that testified, and I think it was 5 or 6 degrees. Then we had testimony of 2-1/2 degrees. Does anybody know for sure what it is? Between 2-1/2 and 8 degrees, maybe more? Does anybody know?

THE WITNESS: Actually I'm not certain where the 2-1/2 degree per second number came from. My analysis has been fairly consistent with this level.

MR. MARX: A might higher rate is what you're talking about?

THE WITNESS: Higher, yes, but certainly not high. I mean, it's nowhere near the rudder capability.

MR. MARX: I understand.

No further questions.

CHAIRMAN HALL: Mr. Clark?

MR. CLARK: I'll be referring back to Exhibit 13-G, page 8, but first if we could look at 13-G, page 18. And if we don't get the viewgraph, don't spend a lot of time. It's a graph called Low Order of Side Slip that shows a side slip rate of about 3 degrees per second.

Is that type of a side slip rate consistent with this rudder angle rate of 5 degree per second or 3 degree per second?

THE WITNESS: Yes. I believe it's quite close. We still need to go back and basically try to bring this analysis together with the simulation analysis.

In this analysis, the side slip is actually -- as I say, a variable that I determined to produce a good match in altitude and airspeed. To really validate whether or not that side slip is realistic, we need to bring this match together with the simulator and get to the point where they're both saying exactly the same thing.

I believe that it is very close and based on the side slip angles that the simulator is getting at and looking at what's happening to the heading angle, still slight errors in the heading angle on those matches. And if you account for that, it would tend to bring the side slip up close to what I have here.

So, yes, I think it is realistic.

CHAIRMAN HALL: Mr. Dellicker, if I could at this point just ask you and the gentlemen at the Boeing table -- and first, let me thank you, obviously, for the time that you have put into this work so far. But there has been several references during this hearing to additional work that you all will be conducting that obviously is going to be an important part of this investigation.

Do we have any -- can you give us any estimate of time frame on how much longer you think some of these projects that you would like to see done might be completed?

THE WITNESS: I believe we're committing to a couple of months, which may be sporting. We'll certainly do our best.

CHAIRMAN HALL: Thank you.

Excuse me, Mr. Clark.

MR. CLARK: I'd like to move back to 13-G, Exhibit 7. These are the coefficients that have been backed out of the match of the data that you've completed?

THE WITNESS: That's right.

MR. CLARK: Do you see any signatures in this data that would be consistent with a thrust reverser deployment?

THE WITNESS: No, I don't. And I did some estimates on that and the amount of differential thrust between the left and right engine associated with a reverser deployment that would be required to generate the yawing moments that we're seeing here would be on the order of 20,000 pounds difference between the two engines. And that would result in a drag coefficient here that would show up as about plus 1600 drag counts, which would be 1-1/2 centimeters positive on this figure. And during the initial upset, the drag tends to be in the negative direction.

MR. CLARK: Do you have the laser pen with the pointer?

THE WITNESS: I don't know if I do or not.

MR. CLARK: If somebody could -- you do?

Would you be able to show us on the chart up there the 1-1/2 centimeters you were talking about?

And basically, if you move the pencil tip over to where the noise starts on the drag plot.

THE WITNESS: On the drag plot about 132 seconds right above the drag.

MR. CLARK: About right in there. And if you move the pen up --

THE WITNESS: Up to 1-1/2 centimeters?

MR. CLARK: There we go. If we had a thrust reverse basically, you would expect to see your plot show a signature up in that range rather than what we have?

THE WITNESS: Right. And that would be basically sustained throughout the rest of the condition, consistent with this sustained yawing moment.

MR. CLARK: As long as the thrust reverser were deployed, if that were the case?

THE WITNESS: Right.

MR. CLARK: And would you -- what would be your expectations for the lift coefficient?

THE WITNESS: I really can't say for sure on that. I'm not sure what the lift interaction would be. I'm not certain.

MR. CLARK: Okay. And on the pitching moment?

THE WITNESS: I'm not certain on that either because of the wing interactions and the tail and such. I'm not certain which way it would go.

MR. CLARK: Conversely or in addition, we've heard theories about various slat deployments and my understanding is that we would have to have a 20,000 pound force at the engine pylon area to generate the yawing moments that you saw.

What kind of forces would we need for a slat to create that kind of yawing moment?

THE WITNESS: It would be probably on the order of two-thirds of that.

MR. CLARK: Basically, you're scaling the distance the distance out to the slat to produce the yawing moment?

THE WITNESS: Right.

MR. CLARK: And then what would you expect to see on the drag plot if we had a slat producing that kind of drag force to create that yawing moment?

THE WITNESS: Well, that would scale, too, so it would be --

MR. CLARK: Just directly scalable?

THE WITNESS: Yes. Approximately. Assuming that it is, yes. Basically, there would have to be a drag force generating that, so yes.

MR. CLARK: The first cut or the first estimate would be two-thirds of the 1-1/2 centimeters?

THE WITNESS: Just -- yes. A very rough estimate, a half to two-thirds of that.

MR. CLARK: And I assume -- or let me ask you. Do you see any evidence of that in your calculations or your data?

THE WITNESS: I haven't seen anything that would lead me to believe that it is a slat, but I would hate to rule it out.

MR. CLARK: No. I'm not asking you to rule it out. At this point, you don't have an argument to make to me that you see that kind of signature?

THE WITNESS: No.

MR. CLARK: On Exhibit 13-G, page 8, there is a spike at about 136 seconds on the equivalent rudder angle and I believe you've stated earlier that that in your estimation could be a result of a vortex encounter.

THE WITNESS: Yes.

MR. CLARK: Based on the sampling rate that we have, it is possible that that spike could be significantly larger than what you've calculated here?

THE WITNESS: I don't believe so. The rate of change of heading angle is not all that large. In fact, I did a study in that little narrow region of data where I went in and I interpolated between the existing datapoints with different curve fits with no significant change.

I managed to drop that peak by about one degree. It was up around 12-1/2 degrees and I dropped it down a little bit just by very careful comparing of the data between the points. Beyond that, I couldn't justify any further change in that data.

MR. CLARK: In that regard, if -- I believe what you're saying if at that point we had no rudder movement that that spike could be generated possibly by the flow field and you're going to continue your work exploring that?

THE WITNESS: Yes.

MR. CLARK: For that type of spike, that

indicates that there are side forces either on the rudder or the horizontal tail. Could the forces that are on that tail producing that spike create -- have the potential to create structural damage either to the vertical tail or the rudder?

THE WITNESS: I don't see anything in there that would cause me that concern. And we're only talking about 10 degrees equivalent rudder here. The vertical tail is designed to handle much more than that. I'm not a structure person, but --

MR. CLARK: I understand.

If we could bring up Exhibit 10-D, page 3, I'd like to ask some questions about that.

If we could adjust that slightly so we could have list A in view, and then we'll move to list B.

My understanding is that you have very extensive experience in handling flight test data.

THE WITNESS: Yes.

MR. CLARK: And you've talked earlier about sample rates of at least 20 hertz or 20 datapoints per second.

THE WITNESS: Yes.

MR. CLARK: Typically on Boeing flight tests, how many parameters do you record or do you capture?

THE WITNESS: A grand total, we record literally thousands on the airplane. However, we -- I normally work with on the order of between 50 and 70, in that area. Significant motion parameters, airplane control deflection parameters and so on.

MR. CLARK: The list that I've provided to you contains numerous parameters that have been recorded on other flight data recorders. And specifically, the ones that have the checkmarks were recorded on the ATR airplane that recently crashed in Roselawn.

Would you -- you were describing control parameters, motion parameters that may be recorded. Would you quickly go down through that list and describe to those -- which ones that would seem appropriate or pertinent that you could use in an accident investigation?

Let me back up. You talked about what you use in flight test. Now you've completed at least one investigation, and I missed earlier, have you participated in other investigations, accident investigations?

THE WITNESS: No. This is my first accident investigation.

MR. CLARK: Okay. Then based on your experience here, if you went down that list, could you define to us the parameters that you would like to see be available in some future accident investigation?

THE WITNESS: Well, certainly everything that is checked. And, of course, as I said before, it would be very useful to have the actual control surface measurements.

MR. CLARK: Thank you. I have no further questions.

The only comment I would make is that for information, the airplane we're dealing with in this accident had the recorded parameters on the left-hand side of the column, including the six parameter list and the 11 parameter list. And then also for information, the Colorado Springs airplane had the six parameters list type recorder.

But I have no further questions. Thank you.

CHAIRMAN HALL: And ATR had all of the items that are checked?

THE WITNESS: Yes. That's correct.

MR. CLARK: They had additional parameters but for the list that we had, they had at least those.

CHAIRMAN HALL: Mr. Schleede?

MR. SCHLEEDE: Have you validated these various calculations and the data that you've produced here today by comparing it with the flight test airplane that recorded flight control positions and lateral acceleration?

THE WITNESS: Yes. Actually, I did a -- basically a two step validation. We validated it against simulator day to begin with to check it all out, and that was based on a simulator match of this condition. And we recorded, as part of that match, all of the motion parameters that we're concerned with, including the size of angle that it produced and angle of attack, and went through, extracted from that dataset just the seven parameters that we had available from 427 and went through this analysis and compared the results against what the simulator had produced for the other motion data and that checked out well.

And I have run through some analysis work, validation work, with actual flight test data. There's another condition that we ordered up to do a final validation and I haven't had time to go back and go through that condition. But I'm satisfied, based on the work that I've done, that the methodology is sound.

MR. SCHLEEDE: So there is flight test data available for you to compare this analysis with to see how close it matches?

THE WITNESS: Yes. We have a lot of flight test data in our database. We don't have any conditions similar to this, but conditions nonetheless that would allow us to validate the method.

MR. SCHLEEDE: It may be evident from your earlier testimony, but would any of this work have been necessary if we had rudder position, aileron position and lateral acceleration recorded on Flight 427?

THE WITNESS: I think that regardless of how many parameters we'd have, we'd probably always go through this analysis just to check the data for validity. But of course, having those extra parameters would eliminate a lot of questions.

MR. SCHLEEDE: Okay. And the last thing. Did you do any similar analysis of the United 737 accident at Colorado Springs?

THE WITNESS: No. I was not involved in that at all. This is my first investigation.

MR. SCHLEEDE: Are you aware of any similar calculations and analysis that have been done on the data from that accident, a kinematic type analysis?

THE WITNESS: I believe that all of the work done on that, what little I know of it, was done basically with just the simulator and trying to match the data as the standard procedure has been in the past.

I think this is the first time that I know of that we've gone through this kind of exhaustive kinematic analysis of the data.

MR. SCHLEEDE: So to your knowledge, there's not been any comparison of the Colorado Springs data to your analysis that you've described today?

THE WITNESS: That's right.

MR. SCHLEEDE: Thank you, sir.

CHAIRMAN HALL: Mr. Laynor?

MR. LAYNOR: No questions.

CHAIRMAN HALL: Well, let me first, Mr. Dellicker, thank you for your explanation of a kinematic study. I felt that was well done and very helpful.

And again, let me comment on the work you have accomplished in assisting -- and the time you spent on this assisting the Performance Group in their work. My only, -- I have no questions. My only comment is that you certainly seem extremely able in what you do and I only wish and I will hope that we have more information and more parameters for you to be able to work with.

In this accident we obviously don't. I certainly hope that that's an area the Board is going to promptly look at.

You're excused. Thank you very much.

THE WITNESS: Thank you.

(Witness excused.)

CHAIRMAN HALL: If we would please call Mr. James Kerrigan. He is being recalled. I don't think that's a negative connotation in this situation, Mr. Kerrigan.

Mr. Kerrigan is being recalled to testify. He has previously been sworn. He is, as you may remember, a principal engineer in the Boeing 737 Aerodynamics, Stability and Control Group with Boeing Company in Seattle, Washington.

(Witness testimony continues on the next page.)

JAMES KERRIGAN, PRINCIPAL ENGINEER- 737 AERODYNAMICS,
STABILITY AND CONTROL, BOEING COMMERCIAL AIRPLANE
GROUP, SEATTLE, WASHINGTON

(Whereupon,

JAMES KERRIGAN,

was recalled as a witness on behalf of the NTSB, and, having been previously duly sworn, continued his examination and testimony as follows:)

CHAIRMAN HALL: Mr. Jacky, I believe the witness is yours.

MR. JACKY: Welcome back, Mr. Kerrigan.

THE WITNESS: Thank you.

MR. JACKY: First of all, I was wondering were you present for Mr. Dellicker's testimony?

THE WITNESS: Yes, I was.

MR. JACKY: Do you have any comments or comparisons of the data that was involved in the kinematic study versus the data that was extracted using the backdrive of the simulation?

THE WITNESS: Yes. We have compared the two methods. I've forgotten what the exhibit number is. I believe that's Exhibit 13-N, page 1.

What this shows is a comparison of the side slip angle that Mr. Dellicker determined from his kinematic solution and the side slip angle that was determined from the simulator exercise, and also the equivalent wheel position and the equivalent rudder position.

The top of the chart is the side slip angle. And you can see, there is a bit of a difference between the two. And also, if you look at -- I don't have a plot of angle of attack, but angle of attack also showed some difference between the simulator and the kinematic solution.

As you can see, though, the basic dataset for the two methods is quite comparable. The equivalent wheel position mirrors one another very well during the early portions of the upset. During the latter portions where the side slips are deviated quite a bit, there's a fair amount of difference.

Again, the equivalent rudder angle that's shown, that also shows pretty fair agreement. The kinematic, again, shows a little more rudder than does the simulator, and that's consistent with the increase in the higher side slip angle that's being shown in the kinematic solution.

We're currently in the process -- I should point out that these two exercises were done totally independently in the beginning. It became a good way to check both one against the other to make sure that we were going to get a consistent answer. And up to this point when this data was plotted, the two methods basically have been independent.

What we're currently doing on the simulator is introducing the side slip angle and the angle of attack from Mr. Dellicker's kinematic solution. And we can also on the simulator, with that new information, force the simulator to come close to matching those parameters.

We're in the early stages of that, but the results to date look very favorable. And these two solutions, I think, will close onto a common solution in the end.

MR. JACKY: Thank you.

Now if I could refer your attention to

Exhibit 13-B, page 4, this is the list of the simulator failures or malfunction scenarios attempted. And I know that earlier this morning Mr. Berven and Mr. Carriker spoke to the results of these tests. But I wanted to ask you first of all, did you participate in these scenarios?

THE WITNESS: Yes, to some extent. My group was responsible for the simulation that was used in this exercise. And, of course, the Performance Group of which I was a part was also instrumental in setting up these exercises.

I did not participate from inside the cab. One of the other gentlemen in my group was in the cockpit. However, I was present during those discussions of the results.

MR. JACKY: And for reference sake, that is the M-cab simulator?

THE WITNESS: Right. This was all conducted in the M-cab simulation of the 737-300.

MR. JACKY: Okay. I believe earlier this morning it's my understanding that Mr. Berven and Mr. Carriker both estimated or thought that perhaps out of all the simulators or the items looked here, the best estimate or the best match of what early upset, as indicated by the FDR trace, may have been Item 2(b) and (c), basically the rudder hardover rate somewhere between 2.5 degrees and 5 degrees per second.

Are you familiar enough with the data in order to make some sort of characterization as to that same characterization?

THE WITNESS: Well, I think in terms of the yaw rates that were being set up by that kind of an input from the rudder, along with the pilot's reaction in terms of wheel, that that yaw rate was pretty similar to what was seen in the flight data recorder from USAir 427. However, the oscillatory beginning of that flight data recorder I don't think was really indicated by any of the tests that were done during this simulator exercise.

MR. JACKY: So in other words, none of these were able to match the FDR data exactly?

THE WITNESS: No. Nothing here was very close to that initial roll back and forth. Generally, I think when you put the rudder in at a constant rate, what tends to happen is you get a fairly rapid change in heading angle, but the roll oscillation generally speaking isn't as pronounced.

MR. JACKY: Okay. Now if I can refer your attention to Exhibit Number 10-B, which is Ancillary Flight Data Recorder Study. What this study basically is is a comparison of different plots or different FDR data from USAir 427 as compared to other incidents and accidents concerning 737 aircraft.

What I would like to do is go through each one of these incidences and to look at a couple of the data plots and to get your testimony or characterization of are there any sort of similarities or are the data not similar at all in these instances.

The first one that I would like to concern is the United Airlines 585 accident which happened on March 3rd of 1991. And there are several plots. I believe nine different plots of data. And starting with page number 13 of Exhibit 13-B -- or, I'm sorry -- 10-B.

CHAIRMAN HALL: What page? 13?

MR. JACKY: I believe it's 13. The data may also be in Exhibit 10-E -- 10-E, page 1.

CHAIRMAN HALL: It's page 13, Exhibit 10-B; correct?

MR. JACKY: Yes. But what we've done is taken the pertinent plots and placed them into Exhibit 10-E also.

CHAIRMAN HALL: Okay.

MR. JACKY: Okay. Have you or are you familiar at all with the FDR data from this accident?

THE WITNESS: Yes. I worked on that accident after it occurred.

MR. JACKY: Okay. And in the course of your investigation of 585 and also with 427, have you had an opportunity to compare the two sets of data?

THE WITNESS: Yes. We have looked at the two accidents. And, of course, there are some similarities in terms of what we saw occur on the airplane.

They did roll in different directions. The 585 airplane rolled to the right whereas this one rolled left. And, of course, the 585 airplane was only about 1,000 feet above the ground at the time of the occurrence.

One of the things that is quite different between the two airplane accidents is the weather. In the case of USAir 427, the weather was quite calm prior to the upset. In the case of UAL 585, the weather was quite bad in the area. They spotted wakes or mountain rotors, as they're called. Otherwise sometimes called horizontal tornadoes that occur in that area, in the area of the mountains. And the weather on that day was basically referred to as a weather event, not uncommon in that area.

As I recall, they figured they had probably five days like that a year when the weather was extremely violent.

We have -- well, we haven't found the comparison plots yet, I guess.

(Pause.)

MR. JACKY: I guess we can work on without it, but --

THE WITNESS: Okay.

MR. JACKY: Or unless -- well --

CHAIRMAN HALL: What's the difficulty? Can't find the slide?

MR. JACKY: Yes.

CHAIRMAN HALL: Well, why don't we proceed and somebody go over there and assist and proceed ahead.

MR. JACKY: I apologize.

THE WITNESS: Yes. Some of the plots that are shown in the exhibit for the case of UAL 585 were not available on the flight data recorder, as Mr. Clark pointed out in the last witness' testimony. The flight data recorder on the UAL 585 was only referred to as a six channel and that basically means from our standpoint there are four channels of usable data. They include the load factor, the heading, airspeed and altitude. The other two channels are time and radio transmissions, I believe.

The plots that are included in the exhibit include roll angle, pitch angle, and also pitch and roll rates, which were derived from an NTSB match of that data. That's very -- I think to a large extent speculation.

We also have done a similar match at Boeing and come up with fairly different pitch and roll angles. The one other problem that exists in that dataset is that the directional gyro that's used to determine the heading on that airplane is an old type of gyro or an old type of system for determining heading.

And once the pitch and roll departs significantly from level flight, there can be some very significant errors in that heading, so it becomes very unuseful after say 50 degrees of bank and maybe 10 degrees of nose down pitch. The heading can have an error of 20 degrees and it gets very much worse as you go further in bank. So it's difficult to use that throughout the maneuver.

As to whether there are similar causes to that accident, we really don't know. And the match that we put together which hits all the radar points available during that maneuver and also puts the airplane at the impact site, there was no rudder involved in our match. The rudder was held within the yaw damper's capability.

It becomes very difficult with only four parameters to really accurately determine what happens to that airplane. However, as I mentioned, the weather that day was very bad, extreme, and with indications of mountain rotors in that area. And the winds that we calculated in our match of that data are very much within the winds that were present on that day.

And Boeing believes that the weather in that case was the probable cause. And I think that was part of what was cited in the NTSB final report.

MR. JACKY: You mentioned that it was your belief that the weather was very bad or very turbulent, if I could add that word. In terms of the data, how would that be or where would that be most exhibited?

THE WITNESS: Well, in terms of the data, mainly load factor, the normal acceleration on the airplane, I don't know if it really shows enough -- ah, we have your chart.

If we go down to chart 18 in that set, it shows the normal load factor and if you -- the upset on that airplane, as you look at the time, the time there is from USAir 427. But if you look at the time from 125 to 150, it shows some rather violent load factor spikes. Not violent but very -- they are the same order of magnitude in terms of up and down motion as USAir had laid in the flight, and yet that was the atmosphere that he was flying in.

The upset on Colorado Springs, I believe didn't start until -- on this scale, maybe 150.

Let me look at roll rate. Yes. Somewhere between 145 and 150 is where the actual upset to that airplane occurred. So you can see prior to that there's extreme load factor. It would have been a very uncomfortable flight to have been riding on.

CHAIRMAN HALL: Now, Mr. Jacky, could we get the page number on the record, please?

MR. JACKY: I believe there's a difference in the plots. The one that Mr. Kerrigan is referring to is I believe Exhibit 10-B, page number 18. However, it appears as if the plot that's shown in Exhibit 10-E, page 6 is -- the time has been skewed a little bit.

CHAIRMAN HALL: Well, let's get this confusion resolved here and at this time take a break for 10 minutes until a quarter 'til, and then let's have it back in order.

(Whereupon, a recess was taken.)

CHAIRMAN HALL: The hearing will be back in session. I'm told we're ready to proceed.

Is that correct, Mr. Jacky?

MR. JACKY: Yes.

CHAIRMAN HALL: Appreciate everyone's patience. Please proceed.

MR. JACKY: My apologies.

Rather than attempt to go through all the charts of all these instances, I would rather like to ask you if you're familiar with the listings or with the datasets of these incidents and accidents.

THE WITNESS: Yes.

CHAIRMAN HALL: One moment.

Again, I ask if you're going to have conversations, please take them outside of the ballroom so that those in here we can have the attention and everyone will have the opportunity to listen.

Go ahead. I'm sorry.

THE WITNESS: Yes. We have looked at the majority of them. There are a few that we have barely touched upon, but the majority of incidents and accidents we have examined at Boeing.

MR. JACKY: In the listing of these accidents, as best you can recall, are you aware of any similarities between the datasets off of these flight data recorders and the data traces from USAir 427?

THE WITNESS: We've already talked about the Colorado Springs accident. I think of all the other accidents, the data that's listed there, none of them are particularly similar to this accident in character.

The incidents that are there include it looks like yaw damper type hardovers which are easily controlled by the pilot and don't appear to have been any hazard to the airplane in particular.

MR. JACKY: When you mentioned the yaw damper incidents, to which of the datasets are you referring to?

THE WITNESS: There's one that occurred at San Pedro Sula in Honduras, a Continental airplane. That one in particular was looked at pretty hard at Boeing. We put together a simulation of it and the initial event appears to have been a yaw damper hardover which resulted in only a 9 degree bank angle, which was quickly corrected by the pilot.

We don't understand everything about that event. The yaw damper failure that caused that should have disappeared. The rudder should have returned to center and the rest of the flight should have been normal.

Pilot reports indicate that he continued to have to hold some wheel, and we don't necessarily understand that. We have actually conducted one flight test at Boeing to evaluate that circumstance. And unfortunately, the configuration of the autopilot wasn't quite the same, so we intend to conduct another test shortly to look at this particular incident and see if we can recreate what happened to this pilot.

We don't believe, however, that what happened here would have any bearing on this USAir 427 accident.

MR. JACKY: Are you aware of any other accidents or incident flight data recorder information that might be comparable to USAir 427?

THE WITNESS: Well, in the list of items you've given, there is a 737 -- I believe it was a 500 that got into a wake upset in Denver. And those places basically show some similarities to what we see in the

USAir 427. Obviously it was not a loss of an aircraft or even a serious upset in that case. The airspeed trace shows to be very similar in terms of the airspeed spike that occurs as he enters the wake and also there's a load factor bump that's not dissimilar from what we see in the USAir accident.

And when we -- we have not analyzed this one at Boeing as yet. We do have the data available and we'll be pursuing that in the near future. It does show a fairly significant roll upset to about 20 degrees bank. And while that's not by any means a safety of flight issue, at any time the airplane is banked over and uncommanded and it rolls to any angle it's an area that we're concerned about. We'd like to understand what's happening.

In this case I think this wake may allow us to run through like the kinematic solution and perhaps we can determine if the wake that this guy ran into is similar in magnitude to the wake of USAir 427.

So I think there may be some positive information that will come out of that.

CHAIRMAN HALL: Could we get Mr. Laynor's microphone on, please?

MR. LAYNOR: Just for the record, while you don't have to refer to the charts in this exhibit in detail, could you identify the flights and the pages, perhaps, that the data you're discussing appear on?

I think the first one that you discussed was Continental N17344 and perhaps you can identify the last. That was the Honduras.

THE WITNESS: Yes. That was the Honduras.

MR. LAYNOR: And perhaps you can identify the one that you're discussing when you're discussing the wake encounter by the identification as it appears in the exhibit.

MR. JACKY: If I can answer that, the wake encounter that he's referring to is in Exhibit 10-B, starting with page 22.

MR. LAYNOR: Thank you.

THE WITNESS: Okay. As I said, that is a condition that we will be looking at at Boeing and hopefully be able to get some wake information out of it.

I think that that's something that we will be doing at Boeing. The magnitude of the wake vortex can very probably be determined from wake encounters that occur in -- as long as they have sufficient parameters on the flight data recorders and if the recorder is pulled and sent to us within the 24-hour flight hours after the occurrence, it's possible that we can get some reasonable data out of that encounter.

Preferably, we need it from both the trailing and generating aircraft, which is not always easy to do.

We also, of course, require the weight and speed and configuration of both the trailing and generating airplanes. And success in actually deriving some useful information from that is also going to depend on the weather at the time. An incident like Colorado Springs where it was a serious upset, the weather is such that it's very difficult to deal with the accident from a kinematic standpoint.

What we really need is light steady winds, no gusts to speak of, in order to really fully realize that data.

And one other thing in that regard. We have considered, and I think continue to consider actually going out and flying a 737 behind a 727. We would hope that that would be a Performance Group or NTSB-NASA-FAA and industry representative study that we could conduct and perhaps gain some useful information.

Unfortunately, Boeing doesn't, believe it or not, doesn't own any airplanes, 727's or 737's, so we're going to have to borrow or lease an airplane from an operator or, in the case of the -- the FAA, I believe, has a '27, so we'll be hopefully working that.

MR. JACKY: Thank you.

Earlier this morning, Mr. Berven and Mr. Carriker gave some testimony regarding yaw damper effects and pilots' actions. And there have been some other testimony to that. Are you aware or would you expect to see any sort of yaw damper activity in a wake vortex encounter, especially if we saw some sort of heading change or yawing moment?

THE WITNESS: Well, in any wake encounter what we expect is the bank angle is going to wobble a little bit and there may or may not be infringement of the wake on the vertical tail of the airplane.

In either event, there's going to be some changes in heading, some heading rate that will be set up. And the yaw damper reacts to heading rate. That's what makes it work.

So you would expect that the yaw damper would be active. How much of a control input it would make is going to depend on how violent the rate, the yaw rate is on the airplane.

Generally, I wouldn't expect that it would be going to its full authority but it's possible in an extreme wake that it might.

MR. JACKY: Thank you. Now I'd like to refer you to Exhibit 10-D, please, if I may, and specifically page 3. And we asked Mr. Dellicker this question and I would like to ask you the same question, if it's available.

What parameters that are shown in these two lists would be helpful to you in terms of your investigation? Most specifically, during the backdrive.

THE WITNESS: Well, as Mr. Dellicker said, we certainly could have benefitted in this investigation with any of the control inputs that would have been available and lateral acceleration. Our preferences as an engineer would be to get as many parameters as we possibly can, of course.

We certainly would like to have both the control input in the cockpit and the resulting control surface movement, such as column and elevator, wheel and aileron and spoilers, rudder peddles and rudder position. It also, of course, would be very useful to have the forces involved; rudder peddle, column forces, wheel forces.

Lateral acceleration, obviously, would add a lot of information to our -- as far as lateral directional upsets would be concerned.

MR. JACKY: What would be or is there a benefit in having both a commanded position and the actual aircraft position? For example, say control wheel and aileron position.

THE WITNESS: Well, in case of the aileron, the lateral control system, there's obviously a lot of different components to that. If one of them fails or isn't working for some reason, the wheel won't tell you that if that's the only parameter you've got.

On the other hand, if you have all the control surfaces, you may be able to get by without wheel. We don't know of any failure that would cause the aileron and the wheel to not be in perfect agreement.

In the case of the rudders, however, you have rudder peddle and you have rudder position. The yaw damper is in series in this airplane. The peddles don't move and the yaw damper puts an input into the rudder. So unless you have both of those parameters, you really can't be sure what the yaw damper is doing.

So in that case, we would very much like to have both.

MR. JACKY: Thank you.

Are you generally familiar with the Boeing 727 rudder system?

THE WITNESS: Yes. I've worked on the 727 for quite a number of years as a lead engineer in Stability and Control, so I'm familiar with that airplane.

MR. JACKY: Can you briefly describe the

general differences between the 737 and 727 rudder package?

THE WITNESS: Well, in general terms, the 727 has a split rudder, an upper and a lower rudder. The PCU that drives the two I think you need to talk to some of the systems people about, but my understanding is it's not a dual valve servo. It's a single valve servo on both the upper and lower rudder.

The hydraulic pressure to the rudder on the 727 is much lower than on the 737. The upper rudder has an 800 psi maximum all the time. The lower rudder is 2450 psi on the lower rudder for flaps down operation. And when the flaps are put up, the pressure is reduced to 800 psi.

The other similarities, I guess, are it's a cable driven system, very similar. From the cockpit on back to the tail it's quite similar.

MR. JACKY: What would happen to the airplane if a 727 rudder PCU moved hardover?

THE WITNESS: Well, from a systems standpoint, again, you need to talk to the systems people. I believe that if one PCU was driven hardover, the other one would still be available to counter that input. However, even if both rudders went hardover on that airplane or driven to the blowdown limit, because of the reduced pressure available to the rudder, the amount of lateral control to control it is quite small. It takes about 25 degrees of wheel to keep the wings level with a rudder hardover in that airplane. And that's about 15 percent of the available lateral control.

MR. JACKY: Have you personally been involved in the investigation of any upset occurrences in other Boeing aircraft?

THE WITNESS: Yes, I have been involved in quite a number of accident investigations. As I mentioned yesterday, including the 727 TWA event, I've been involved in a number of windshear accidents that have occurred on the 727 and some -- and also at least one 707 accident that I can recall.

(Pause.)

MR. JACKY: I have no further questions.

CHAIRMAN HALL: Any questions from the parties?

Yes, Captain, with the Airline Pilot's Association.

CAPTAIN LeGROW: Thank you, Mr Chairman.

Good afternoon, Mr. Kerrigan. Just a couple of quick questions.

First of all, you testified earlier that in the USAir 427 accident the airplane rolled and upset to the left. You also stated that the Colorado Springs United Airlines 585 airplane rolled and upset to the right. Is that correct?

THE WITNESS: Correct.

CAPTAIN LeGROW: Is it not true that both USAir 427 and United Airlines 585 both rolled and upset in the direction in which they were turning at the time?

THE WITNESS: Let me -- if I could check the record. I don't remember off hand. I believe the -- yes. I believe that's right. That's correct. It was a 20 degree bank.

CAPTAIN LeGROW: Thank you.

Also, you stated earlier that the Colorado Springs 585 United accident, the Safety Board believed that the accident was weather related. Is that correct?

THE WITNESS: They had I believe cited that as a possible cause.

CAPTAIN LeGROW: To my knowledge, and maybe I missed it, but did the Safety Board find a probable cause for United 585?

THE WITNESS: I don't know that they found -- they positively identified a probable cause. I said a possible cause, which is a bit different in their terminology.

CAPTAIN LeGROW: Okay. Thank you. I have no further questions.

CHAIRMAN HALL: Other questions from the parties?

Boeing.

MR. McGREW: Yes, Mr. Kerrigan. Two questions.

Would you comment, please, on the sample rate and your views of what data recorder sample rates might be doing to our analysis?

THE WITNESS: Okay. Yes. As Mr. Dellicker mentioned, the sample rates, particularly for the kind of analysis that he is conducting for the kinematics, is quite important and an increased sample rate would benefit that kind of an analysis very much.

From a simulator standpoint, there's also benefit. It would be extremely beneficial, I would think, to have things such as heading at much more than a one sample per second rate.

MR. McGREW: Thank you very much.

CHAIRMAN HALL: Any other questions?

Mr. Marx?

MR. HAUETER: Excuse me, Mr. Chairman. There's a question in the back.

CHAIRMAN HALL: Okay. Yes.

Mr. Wurzel? Wurzel. I'm sorry. Yes. With the International Association of Machinists. Please --

MR. WURZEL: One question, Mr. Kerrigan. A few questions here.

To your knowledge, is it not true that UAL Flight 585 had reported uncommanded rudder movements during previous flights?

THE WITNESS: My understanding is that there had been some pilot complaints about that airplane and that some steps had been taken to try to correct that in the rudder -- the yaw damper control system.

MR. WURZEL: And also, the weather in Colorado Springs, I believe you stated, was kind of questionable that day, but the weather report shows it was VFR with 32-35 miles an hour gusts. Lighter aircraft than the one that had crashed had landed before that.

Do you know anything about that?

THE WITNESS: That's very possible. The onset of what was called the mountain rotor is something that's very localized. The size of a mountain rotor can vary anywhere from probably airplane size, 100-200-300 feet across, to up to perhaps a couple of thousand feet across. And airplanes could be landing safely if they didn't encounter such a -- the rotor, and still have an airplane that gets into the core of the rotor and has control difficulties.

MR. WURZEL: In that area, do you know of any other aircraft that had ever encountered any of those large type rotors?

THE WITNESS: I don't know that there had been any specifically in Colorado Springs. People that fly in that area, as I understand it, frequently do encounter mountain rotors, generally on that side of the Rocky Mountains there's, I believe, encounters.

I can't specify one for you right now but there have been other encounters.

MR. WURZEL: That concludes my questions. Thank you.

CHAIRMAN HALL: Thank you.

Mr. Marx, you have no questions?

Mr. Clark?

Mr. Schleede?

Mr. Laynor?

The Chairman's only question, I believe we're going to have some individuals from Boeing that are going to be testifying much later in regard to the reporting system -- no, no. On incidents that occur in regard to the stability and control of the Boeing 737.

Is that information routinely provided to you, sir, and what is your role in that, as things are reported, that may occur with the number of planes that are out there operating?

THE WITNESS: Well, that's one of the primary jobs of my group. We deal with customer inquiries of all kinds. If an event like that is reported by an airline, it comes in through Boeing Customer Service or Flight Operations and somebody along the line makes a judgment as to whether we need to be involved.

We don't automatically see every telex that comes in. Of course, there's several thousand of those I believe a day. It's a large number that arrives, most of which don't involve stability and control.

But if it does involve the stability and control of the airplane, it should be passed on to us and I'm sure the majority of them are.

CHAIRMAN HALL: And just one more observation. On the flight data recorder where you mentioned a number of things you would like to have, I assume that the state of technology is that those things are presently available if an airplane is properly equipped with a flight data recorder and the electrical ability to get that data off?

THE WITNESS: Well, certainly the new

airplanes that are being produced have all of that data, or most of it, recorded already, and it is available. On the older aircraft it becomes a concern because some of the parameters that we would like to have that I would like to have recorded are not necessarily readily available. So it isn't clearcut that all aircraft out there, large jet transports, have it readily available, the information we'd like.

And some of the parameters that I would like to see, such as pilot forces, I don't know any of the aircraft currently being produced include instrumentation currently that has that has that information available. I think the technology to add that to the airplanes is probably there if we're willing to pay the cost.

CHAIRMAN HALL: Okay. Well, Mr. Kerrigan, we appreciate your appearing once and appearing twice. I don't know whether we'll have you back for a third time, but at this point you're excused.

THE WITNESS: Okay.

CHAIRMAN HALL: Thank you.

(Witness excused.)

CHAIRMAN HALL: The next witness is Mr. Bernus Turner. He also is with the Boeing Commercial Airplane Group out of Seattle, Washington. He is the Boeing 737 Flight Controls Engineer.

(Witness testimony continues on the next page.)

BERNUS TURNER, B-737 FLIGHT CONTROLS ENGINEER, BOEING
COMMERCIAL AIRPLANE GROUP, SEATTLE, WASHINGTON

(Whereupon,

BERNUS TURNER,

was called as a witness by and on behalf of the NTSB, and, after having been duly sworn, was examined and testified on his oath as follows:)

MR. SCHLEEDE: Mr. Turner, please give us your full name and business address for the record.

THE WITNESS: Full name is Bernus Gene Turner. Address is Box 3707, Seattle, Washington 98124, I believe it is.

MR. SCHLEEDE: And you work for Boeing?

THE WITNESS: I do work for Boeing. Have almost for 34 years.

MR. SCHLEEDE: In what position?

THE WITNESS: I'm currently the technical manager of mechanical systems for the new generation of 737.

MR. SCHLEEDE: Give us a brief description of your background and experience that qualifies you for your current position.

THE WITNESS: In 1961 I graduated from the University of California, mechanical engineering. Came to work directly for Boeing on the 727 project. Went over to the 737 project as a lead engineer in 1964 or '65. Left there in '69. Worked on a variety of other Boeing airplanes.

In 1986 I had been made a part of management and I came back into the 737-757 project at that time as a hydraulic supervisor. Stayed in Sustaining. Moved up to unit chief in that same project and a year and a half ago went to the new generation 737 project.

MR. SCHLEEDE: Thank you. Mr. Phillips will proceed.

MR. PHILLIPS: Good afternoon, Mr. Turner.

In your experience, your 34 years with Boeing, you've been involved with flight control systems and hydraulic systems design for the extent of your career. And I also note that you hold some patents. Do any of those patents apply to any of the flight control systems on the aircraft that we're looking at today?

THE WITNESS: No. I think I have six active patents. None of them happen to be on this particular airplane, though.

MR. PHILLIPS: All right. And over the years of your design experience, how long of that has been -- have you been involved with the 737 program in general?

THE WITNESS: First assigned to the 737. I was the second hydraulics engineer assigned to the program in 1964-65, something like that. Left it in '69 as the lead engineer for flight controls working power control packages. And like I said before, I came back to the program in 1986 as a manager and have been associated with the 737 in one capacity or another ever since.

MR. PHILLIPS: In the course of your duties at Boeing, have you been involved in any of the accident investigations involving 737 aircraft?

THE WITNESS: Yes. I was active in the Colorado Springs 585 at the time. This particular program or accident I've not been directly associated with it. Some time ago, I was asked to come in and take a look at what the systems folks were doing, offering expertise, any background, any experience, anything I might be able to add to the program.

MR. PHILLIPS: With Mr. Chairman's indulgence, we've made several attempts today and in the last couple of days to talk about the flight control systems. Pilots have describe it and Stability and Control people have described it. And what we'd like to do is ask a systems person to take a stab at explaining some of the functions of flight control systems.

Mr. Turner is prepared to go through the systems with the general description and we'll stop and get more specific in the areas we're interested in. So if you could start us off, I think we're referring to Exhibit 9-S this time.

CHAIRMAN HALL: Are we going to show a number of slides again as we go?

MR. PHILLIPS: Yes.

CHAIRMAN HALL: Well, let's see if we can't do something about the lights so everybody can seek.

Thank you, sir.

MR. PHILLIPS: What I'd like to start with is just a general description of all the flight control systems and as we get into the systems, a little more specific about the rudder control system.

THE WITNESS: The airplane is very conventionally laid out. Ailerons and spoilers on the wings which we've seen in this chart before. That's used for lateral control. The pitch control is basically an elevator, a pair of elevators on each side of the airplane with a movable stabilizer for trim.

A single rudder for directional control which incorporates both the main rudder throw and the yaw damper control.

CHAIRMAN HALL: Pitch is up and down?

THE WITNESS: Pitch is up and down. Yaw is sideways. Lateral is roll.

Fundamentally, if we look at the next chart what one can see there is the airplane is basically a hydraulically fully powered control airplane with a manual backup. What that really says, that we have primary flight controls on two hydraulic systems. If the two hydraulic systems are inoperative, there's the cable system. That is, the airplane can in fact drive the surfaces directly through pilot effort.

If you'll look at the elevators, there's a set of control columns, one for each pilot, in the front of the airplane. Two sets of cables go back to the tail of the airplane. The cables run pretty much right underneath the floor and the floor beams.

In the tail of the airplane we have two single system hydraulic packages bused together on a single bus torque tube. The output of those two packages go through a set of push rods out and drive the elevators.

It isn't clear to se here but the input cranks that are connected to the cables, motion comes in and that commands the package to go up or down. If the package is inoperative because of no hydraulic system pressure, then there's some manual stops about two degrees, 2-1/2 degrees -- something like that -- backlash, and that link would bottom out. That enables the pilot to drive the surface directly through pilot effort.

Needless to say, the forces to operate the surfaces directly without any pilot boost are somewhat higher, considerably higher than the power to just move the controls directly.

The next chart is the stabilizer control system, the other half of the pitch control system, and there's a jack screw at the tail of the airplane that pivots the whole stabilizer. That's an electric system where there is trim switches on the control columns, and through the trim switches you have an electrical signal that goes back to this jack screw driven by an electric motor, and that can position the stabilizer directly to the pilot's trim commands.

We have a cable system and a crank, so to speak, in the front of the cockpit, a stabilizer trim wheel. And by turning those trim wheels you can manually position the stabilizer as a backup.

So between the elevators and the stabilizers you manage the pitch control of the aircraft.

The lateral system gets to be a little more complex. As Mr. Rusho described earlier, you start with the two control columns, the wheels, and a set of cables that drive down into the wheel well. Signals off of these cables go down and drive the main power control packages. They happen to be identical packages to the elevator, single system driving on a single bus torque tube.

The signals go into the packages. The packages respond in the appropriate direction, drive the cable system that actually drive the aileron. The other set of cables go over to a spoiler system and through the spoiler mixer box, they drive spoilers to augment the ailerons.

There is an override protection device. If for some reason or another the ailerons become jams, one can, through the co-pilot's wheel, rotate, go through and override mechanism on the bottom of the co-pilot's column there and drive the spoilers directly. So there's jam protection in there.

The rudder peddle is the one system that does not have a manual backup. Here we have a third hydraulic system and another hydraulic power control package.

At the front of the airplane is two sets of rudder peddles. This particular chart shows one. There's a set for each pilot and co-pilot.

The rudder peddles themselves drive a linkage train; goes back and drives quadrants. The quadrants are bused together from right-hand to left-hand side of the aircraft. They run a single cable system. The single cable system goes back to the tail of the airplane with a field and centering unit.

And let's see. Probably in the next chart there's a little bigger scale on the field and centering. There's a field and centering unit there in the tail of the airplane, and what that really is is it's a cam and spring. And when the pilot moves the rudder peddles he actually moves that cam and spring and that gives him an artificial feel he's pushing against something.

And so when you push on them, you can -- you know, just by -- I think its about a 12 pound, 12-15 pound brake up to about 150 pounds, you get tactile feedback off of your field system. And then that same control quadrant is attached to a torque tube. The torque tube transmits signals to the main rudder power control package as well as simultaneously transmitting signals to the standby actuator.

So fundamentally, you mash on the rudder peddle. That moves the cables. The cables move the field and centering unit; moves the linkage train that tells the main power control package where to go and it positions that way.

In the event that the main rudder power control package, which is a dual hydraulic system, dual load path unit, is operative, two hydraulic system fails, then the third hydraulic system is actuated and that power is slowed to the standby actuator, which is the single system, single load path system.

So fundamentally, most of the time when you use standby package is if you happen to be on a manual reversion, then you have the rudder to augment your elevator and lateral manual system.

The next chart gives somebody an idea of the complexity in the dual load path dual system hydraulic power control package. Rather than try to get into the details of how this thing works, I think it would suffice to say that through an input linkage you get a signal that comes in through an interior set of linkages and drives the main control valve, which happens to be a dual concentric tandem device. It's a valve within a valve and there's two hydraulic systems, so it's a tandem valve.

We'll get into -- I think Paul Cline has got some videos later on that may help explain how this complicated linkage works.

Incorporated in there is a yaw damper actuator. That's a piston that's driven by what we call a transfer valve. The transfer valve takes electrical signals, converts them to hydraulic signals, goes down and moves this yaw damper piston. The yaw damper piston moves. It drive the linkage train and via the feedback linkage, the rudder moves in direct proportion and only as far as this yaw damper piston can move.

So if it doesn't move, the rudder doesn't move. If it moves the equivalent of three degrees, which is on this airplane, that's how far the rudder can move.

Incorporated in the power control package, as well as the main power piston, is a series of bypass valves. And incorporated in this bypass valve is an orifice. And the function of that orifice is to bypass fluid from one side of the piston to the other.

We found when we fired up our fight control tests quite some number of years ago, the system was unstable and had a limit cycle. It would sit there and shake back and forth, and so we had some changing of gains within the servo system to do. And one of the things we did to add stability to the system was put this bypass orifice in there.

And so any time you have a small command to the package, the first thing that happens, fluid flows through the orifice and then as you put large commands, you swamp out the orifice and the rudder package actually moves.

Also incorporated in there is a couple of filters -- and we'll probably talk about filtration a little later -- to filter any incoming fluid that comes into the package. There's also an interconnect check valve and that interconnect check valve keeps fluid from ever flowing backwards through the package. And we'll probably talk about that a little bit more.

Why don't we skip on to chart Number 9.

Greg, I'm just following the outline here, so just jump in if you need to.

MR. PHILLIPS: That's fine. We'll back right back up where we need to ask some questions.

THE WITNESS: Okay. Page number 9 is the standby hydraulic power control package and it has a double bypass, if you want to call it that. The main control valve has a dead band in it, so that any time the command signals is within one degree of the position of where the rudder actually is, the valve just has a bypass that bypasses both sides of the piston to each other.

It also has a bypass valve in it that's pressure operated. And what that double bypass is for is the airplane is certified to be good for any single failure and so since we have two bypasses here, this prevents having a hydraulic lock so that the main power control package would be forced to not move if this thing malfunctioned. And so we have bypassed the main control valve and then a bypass valve. So we always have freedom of motion for the main rudder power control package.

So this thing is really just a manual control. It happens to be what we call a moving body package. The body itself is mounted to the rudder and when you put an input in from the pilot's rudder peddle, the input crank moves, and then the body moves to reestablish the non-relationship of the crank to the body, and that gives you what we call an integral feedback and positions the rudder directly proportional to what's commanded by the pilot.

Now, I indicated that this was a single load path versus a dual load path to the main package. And we have to be good for any single failure. What that says -- next chart, please. What that says is that if that control linkage fails to move, if there's a binding, if a bearing is bound up, if the main servo valve has got a chip in it, no matter what someone may be able to postulate, if that crank can't move the airplane still has to perform satisfactorily.

Very early on we put a shear-out in. That circled area there is where we had a shear out, and the idea was that if you did in fact have a valve jam and stopped this thing from moving, if you pushed on the rudder peddle you could cut the shear-out off and regain control of the main rudder power control package.

What we found when we started testing this device in the iron bird in probably 1967 or '68, somewhere thereabouts, is that part labeled torque tube is in reality a spring. It has enough spring rate to it that when you fix the input rod on the standby package, when the rudder commands came in from the cable system at the bottom of that torque tube, the torque tube would wind up or twist and give you direct connection to the main rudder control package.

And it turns out that there was enough twist in that torque tube that you just moved the rudder with respect to normal commands, even though there was a jam in the input rod of the standby package. And the thing would drive to the limit of stop and we couldn't actually cut the shear out, so the shear-out was taken out.

So, the shear-out was taken out. I think we only had 20 some airplanes that way and probably all of them have been retrofitted.

So what we have there is a built in compliance, the springiness in that tube. All you'd have to do is put your feet on the rudder peddles and/or the feet on the centering unit to provide enough force to wind up that torque tube and position the rudder in whatever position one would want to put it.

MR. PHILLIPS: I believe we were referring to -- you were describing page 10, which we evidently don't have a viewfoil for. Have you got that?

THE WITNESS: Okay.

MR. PHILLIPS: I think we were discussing 10 with the shear-out mechanism.

THE WITNESS: Right. It looks very similar to your other one. It just has the location of the shear-out that was in there originally.

MR. PHILLIPS: Are there any novel or unusual features in the design of the 737 directional control system?

THE WITNESS: In think you're probably referring to the dual concentric servo valve, which has gotten a lot of discussion.

A little bit of history. During the design of the 727 we were looking at various methodologies to take care of a phenomenon known as valve jam. If you drop a chip or some such device, a large particle contaminant into a servo valve and the valve fails to respond, then that particular servo package would in fact start to continue to go in the direction it was commanded to go without feedback shutting the valve off.

There's a lot of ways to take care of that situation and different manufacturers, different people have come up with different ideas. They tend to run in valve jam detectors, mechanical and electrical, and then detect a valve jam. And then usually electrically turn off a valve that depressurizes the hydraulic system and stop the runaway.

Well, this kind of a device, which is pretty commonly used, requires some time to detect the valve jam, then turn off the system, then bleed it down. And so there's a dynamic situation where if you have a valve jam you get some kind of overshoot or you can get the system turned off.

The fellows that worked on the 727 in this particular device -- I was not one of them right at the start of it -- came up with a valve within a valve and the objective of this valve was that it would -- if you had a jam of the primary to the secondary because of a chip, then the secondary would move and you would actually dump both sides of the piston to return pressure, which would depressurize the package automatically with no time lag, no sensing, no electronics, no maintenance, the things that go wrong with electrical systems.

So, this device was intended to reduce the pressure ideally so you could manufacture everything exactly down to zero residual pressure across the piston head. Of course, you can't do everything perfect, so it's set up to reduce the pressure somewhat. And the amount that it has to come down is a function of where you happen to be using this thing; the rudder, elevator, wherever.

Well, we put that on the 727 and it turns out the guys that did the design got real clever. They found that if the valve -- they could set up the pieces so that if the valve jammed in any position except its extreme travel, then you could retain some control over the package.

If it jammed at neutral, for instance, then the secondary would give you full hinge moment at 50 percent rate. If it jammed at full stroke of the primary or secondary, then you ideally got zero hinge moment at zero rate. And if it jammed anywhere in between, then you got some benefit.

So what turned out being an automatic depressurization device also provides some amount of control, depending on where the jam occurs.

Working on a 737, since this device was available, people recognized that if they put this in the rudder of the 737, that if a valve jam occurred, which historically, that happens on a package about once every 10 million flight hours, then this thing would reduce the amount of residual rudder that would be there after a single valve jam or provide control, depending on where the jam was.

And if you could reduce the amount of hinge moment after a valve jam, then you increased your amount of aileron residual that you had over rudders.

I heard a couple of times where you trade off rudder versus aileron.

MR. PHILLIPS: At least two Boeing airplanes that I'm aware of, the 727 which we discussed earlier and the 747, have two rudder panels and independent actuation packages. Can you discuss a little bit the reasoning that Boeing had at the time for going to a single package, dual concentric controlled system?

THE WITNESS: The preliminary design fellows, when the airplane came out of PD, it had a single rudder. I'm not exactly sure what it was. I suspicion that it had to do with -- on this particular airplane, configuration. It was probably lighter than a dual rudder. That would be my guess.

Every airplane is different. The weight tradeoffs are different for every airplane. And I know that's a tradeoff that caused us to put a single slab rudder on 757.

MR. PHILLIPS: And the 777, the triple 7, has a single panel rudder?

THE WITNESS: Let's see. That's the one commercial airplane I haven't worked on. Yes. I believe it is.

MR. PHILLIPS: I don't know if you discussed the rudder trim system. Could you briefly describe how that operates?

THE WITNESS: Yes. I guess I skipped that.

If we go back to page 6, I believe, would show it. On page 6 I commented that there was a field and centering unit that -- when that's driven out of its centered position, you get a rudder position through the input linkage there.

What we do is to have an electric drive motor and a little jack screw, and we actually rotate that field and centering unit with a command of the switch in the cockpit. So, by rotating a rudder switch on the aisle stand, the little jack screw through an electric signal, will rotate the field and centering unit. And what that does it backdrives the cable system positions, the rudder peddles offset to the potion that's commanded, and moves the rudder over to offset that's driven in by the trim system.

So we can trim up to about -- I think it's 14 or 15 degrees of rudder. And when you do that, the rudder peddles are about 50 percent offset away from their neutral position. The rudder peddles themselves are tied directly through the control linkages to the rudder itself through the main power control package.

It does have those manifold stops that I indicated that the elevator package has, and that means that the rudder position to the rudder peddle can only be different by the amount of that small backlash that's in the manifold stops. So the rudder peddles will always follow physically the rudder, regardless of what happens on the ground, the wind blows it, you name it.

MR. PHILLIPS: I guess that brings us to the yaw damper. That's the one time the rudder peddles don't follow the rudder position.

THE WITNESS: That's correct.

Inside the package, as we commented, we have a separate set of summing levers is what we call them. And for that very, very limited stroke the -- let's put it this way.

Within the 6 degrees that's in the valve -- I think it's around 6 degrees. It's in the valve backlash. The yaw damper can move the rudder peddles three degrees, or move the linkages three degrees without it getting back to the rudder peddles. And so we have what we call a series input system where the actual rudder position is a function of rudder peddle plus the year damper.

And so as long as we stay within the valve stop -- and the yaw damper certainly does -- then the yaw damper can put a 3 degree input in. The feedback linkage comes back and that doesn't feed back to the rotor peddles. That's correct.

MR. PHILLIPS: What limits the yaw damper input to 3 degrees?

THE WITNESS: It's the length of the piston and the mechanical stops that it drives up. Again, the piston is only so long and it can move about three-tenths of an inch. That's the -- that it's in. It's in cab, so it can only go two-tenths of an inch or whatever the exact number is.

MR. PHILLIPS: Could you take us back up to the front of the airplane with the coupler and bring us through a description of the yaw input command from the coupler back into the yaw damper and what the resulting motion of the rudder would be?

THE WITNESS: Are you asking me is there an indicator in the cockpit?

MR. PHILLIPS: That would be part of the system. I'd like to -- I'd like to start with the beginning of the sensing of a yaw input requirement and then resolve that into the rudder movement.

THE WITNESS: Fundamentally, when the airplane yaws or swings sideways, we have devices called rate gyro, and it's a gyroscope. And as the airplane rises, the gyroscope creates an electrical signal in proportion to how fast the airplane changes direction.

That electrical signal is processed through a yaw damper coupler, a magic black box that I can't add too much to. And the computated signal goes back to the rudder package. That commands the transfer valve. The transfer valve puts fluid to this little yaw damper cylinder or yaw damper piston, moves the piston, and then that opens the valve.

The rudder itself moves. The feedback

linkage comes back and shuts the valve off, and then that's it in a nutshell, I guess, unless you try to get me to explain the black box.

MR. PHILLIPS: I believe we'll pass on that.

And there is an indication in the cockpit of the yaw damper operation position?

THE WITNESS: There is a yaw damper position indicator and it indicates the position of the yaw damper piston electrically. I believe it's an electrically driven indicator in the cockpit, yet.

And again, I'm not sure if that's basic or a customer option. I believe it's basic.

MR. PHILLIPS: In later testimony we were planning to talk about a series of yaw damper upsets or events over the last few years. Can you speak in general terms of your knowledge of those upsets and events?

THE WITNESS: I understand there has been a number of upsets. Most of the upsets have probably been classified as nuisance things. There have been some where people have sent in reports.

For the most part we've had dirty, noisy or otherwise rough output, electrical output rate gyros, that give an erratic electrical signal. So what you get is probably a quivering or probably a lot of the complaints have been that the yaw damper is not working very good and doesn't damp the Dutch rollout. And it's of course, a right quality, and if the airplane is bouncing around in turbulence, we get write-ups from that, too.

MR. PHILLIPS: Are you aware of any claims of the yaw damper moving the rudder beyond it's three degree limit in this airplane?

THE WITNESS: The answer is no. The yaw damper piston is mechanically limited to what it can go to, and that's that.

MR. PHILLIPS: Going to the standby system that you described earlier, could you -- the term galling needs to be defined. Could you please give us a description of what galling is and what it's effects may be to the standby input system?

THE WITNESS: When two pieces of metal are rubbed together, the little microscopic peaks kind of rub the tops off each other and eventually when you do this enough you get metal transferred between the two pieces.

Not being a metallurgist, I'm not sure exactly what the official thing is, but I think we've all seen on our cars, working on our cars, we have a cap that's rotating in a bushing or something and we get this scratched and rough surface on the shaft. That would be galling. It's really the two pieces rubbing against each other, riding together, breaking loose, riding together, breaking loose and causing a very rough surface.

So that's what galling is to my understanding.

MR. PHILLIPS: Okay. And on the input bearing or the input shaft of the standby actuator, what would be the effect of galling? What could be the effect of galling for that system?

THE WITNESS: Eventually if one were to do it long enough, I guess the galling could get to the point where the two parts wouldn't rotate any more. What we have found a couple of time and several times in service, and we looked at this extensively on a past problem, is that as the galling starts to progress, you start to get a resistance to motion and that resistance to motion, looking at the standby package as the housing moves back and forth, the input link if there's no pilot input stays stationary, and so that link would move back and forth with respect to the housing.

It's a rotary joint and as that rotary joint gets sticky or has high friction, eventually if you had high enough friction it would start to backdrive the input crank and start to be loaded by the field and centering unit. And the field and centering unit then would at some point, depending on how much stickiness is there, would break the stickiness loose and cause the input crank to return to neutral. And that could very well cause very small rudder motion as this thing is progressing along and this galling comes up, causing the field and input centering unit to kick in and out of center, so to speak.

MR. PHILLIPS: Are you aware of any conditions in the accident airplanes that we've been investigating that galling was found on that bearing?

THE WITNESS: Yes. 585 was galled and that particular airplane, it was galled and at the same time the input nut was backed off 30 degrees. What we believe happened there was as this lever moved back and forth and the galling progressed to some particular point, we believe -- I believe at least that the main rudder package was probably removed. The rudder was moved to one side, which is about 30 degrees. The galling was pushed into an area where it wasn't working on a daily basis; stuck; and then when the main package was reinstalled, the nut unscrewed.

Then after that, the indication that we had on another airplane that we found in service with a nut unscrewed, the nut just screwed in and out and operated perfectly normal.

And I guess you're also wanting to know if we had galling on 427. The answer is a small amount of galling. I compared the pictures between 427 and 585 and the series of test samples that we ran to investigate 585, and the amount of galling was very, very much smaller than what I saw on 585.

My understanding is that when the 427 package was tested, we were you might say fortunate that the rudder system was in the fin and the fin broke off and was outside the fireball, so we had pretty complete pieces there. That package had less than a half a pound friction in it, and a half a pound is the limits for a brand new package.

So I would have expected that package to be operating totally normal.

MR. PHILLIPS: What would the effect of galling be in the system if you were to run into it in the normal course? Would it make an input to the rudder or would the pilot know that it was galled?

What conditions would it take for a pilot to realize that the airplane was in that condition?

THE WITNESS: We had several cases in 1986 and the write-ups turned out erratic steering, which is basically high friction in the rudder peddles. The pilots could feel it and had some complaints of erratic yaw damper. And it's kind of difficult to really say what erratic yaw damper is.

For the most part, I believe it's small inputs that they don't expect in smooth weather or probably rough rides when they expect the yaw damper to take the turbulence out in heavier weather. That's how the ones that we found have been written up.

MR. PHILLIPS: Could you characterize what may cause the galling? You described it as peaks rubbing and contacting each other. What would cause the galling?

THE WITNESS: Didn't bring a picture of it, but it's a shaft and a bushing and it's hard stainless steel and a relatively soft stainless steel combination. Harder shaft than is the bushing, I believe.

Generally speaking, if you have a soft material and a hard material, you typically don't get galling very much. If you have two hard materials or two soft materials you can get galling quite readily.

What we have on this package is fairly tight clearances, 2 to 4 ten-thousandths of an inch diametric clearance. We found when the parts were invested in 1986 that we had parts that were slightly out of tolerance or when you're trying to hold something within one ten-thousandths of an inch diameter, it doesn't take much of a lump or out of round to fill up that clearance, drive the two parts together.

We found that for the most part, although it's not universally true, that parts that galled were quite low time parts that were discovered early in the service life, within a couple thousand hours. Not all of them, but most of them.

I guess we had one other case where you could screw the nut in and over-torque it and work it, and that would take up the clearance. In fact, that's how we managed to do our test parts, the testing that we did for it. Reduce the clearance and over-torque it and get the two parts to rub against each other.

MR. PHILLIPS: On the subject of contamination or particulates in hydraulic fluid, could you characterize or describe any testing that's done or any specifications that control contamination limits in hydraulic fluid and the effects on the system?

THE WITNESS: The procurement specification, which we call BMS3-11, defines the cleanliness level for brand new fluid. We have an internal Boeing specification that we use to check the cleanliness of airplanes before we send them out the door, and also to check our hydrant systems to make sure the hydrant systems stay clean.

There's been a lot of sampling done on 427. I think a later engineer has direct knowledge of those exact samples and can give you more data on exactly those samples.

MR. PHILLIPS: Is contamination a design consideration in the original design?

THE WITNESS: Maybe we can start and talk about a hydraulic system and why you put filters and where you put them.

MR. PHILLIPS: That would be fine.

THE WITNESS: Okay.

If you think of a hydraulic system in general, you have a power source which is a pump. The pump is a piece of rotating equipment. Rotating equipment wears out, has wear particles. And so we start with putting a filter on the outlet of the pump.

That filter on Boeing airplanes is a 15 micron filter. Since we're going to talk about microns, why don't we throw something up to kind of identify what a micron is to start with.

Foil number 11.

(Pause.)

To get an idea when we're talking microns and cleanliness, there will be a lot of discussion about 10 microns, 20 microns. How big a piece is this thing?

A micron is 39 millionths of an inch. It's an awfully tiny thing. If you compare it to something that we have a basis for judgment on, say human hair, if you look at the outer circle, that would be a human hair. If you look at that little dot down there, that's a micron.

When we talk about contamination and cleanliness, we keep our systems so clean that what we're talking about are these minute little dots. I've heard it described as if you see the dust floating down on a sunbeam, you're talking about stuff that's that small and smaller. We keep the systems very, very clean.

So, when you talk about a micron, that's what we're talking about. You can see it on the screen. It's a pretty tiny thing.

Incidentally, if you get down and filter the fluid in a 2 to 3 micron range, you actually can filter the coloring dye that's in the fluid out. It's that fine.

So, back to hydraulic systems. The general idea is to arrange your hydraulic systems in such a fashion that you get rid of the wear particles. You collect the wear particles, put them through a filter, and arrange your system such that wherever wear particles are generated, you collect them and get them in a return system.

So you start with a pump. The pump can generate wear particles. You put a filter on the downstream site of the pump, take the filter fluid, put it into a piping distributor system, a pressure system, take that fluid and drive it back to a component, a critical component, such as flight control packages.

We put a filter in the inlet of the package and that's there to make sure that even if there's something introduced into the system say during maintenance when you have a piece of plumbing apart, that you can catch that contamination.

Then in the various components, we arrange the flow passages such that wear particles generated within the various components go into a return cavity. The return cavity collects the wear particles, pushes them out into -- just flushes them, I guess I should say -- out into the return plumbing.

The return plumbing flows back to the main system filter which we use to keep the system primarily clean. And then we put check valves in various parts in the return line so that you can never run backwards and get any wear particles going back upstream. It always has to move downstream.

We collect the wear particles in the return filters, put the fluid into a reservoir storage place for extra hydraulic fluid. From there, put it back into the pumps and recirculate the system.

So, the filtration starts out with find a way to collect the wear particles; take care of the various sources where the wear particles are generated; collect those things; get them back to the return system; take them out.

We manage the cleanliness of the airplanes by the micron level of the filters. The pressure filters outside the hydraulic pumps are 15 microns. The K-string filters, which is the cooling pumps, is 25 microns. I guess 25 microns is what we have at the inlet of all of our flight power control packages on this airplane.

MR. PHILLIPS: I think we're going to hear some testimony later on that in some of the fluid samples collected from the accident airplane that we found some particles in the 25 to 100 micron range. What would be your explanation of finding those particles in the area of the power control unit that they were collected from?

THE WITNESS: Well, again, the data that I looked at, the particles, the lion share of the particles, were in the return cavity where wear particles within the package that come off are collected in a return cavity and then flushed on back to the return system. So in the return cavities and the linkage cavities, that's where one would expect to find the various wear particles.

And again, a 50 micron chunk of wear particle is an awfully teeny, tiny thing.

MR. PHILLIPS: Going back to maybe before the original design was conceived, can you describe some of the Federal Aviation Regulations that define aircraft systems design in view of systems failures, jams and what general protections are designed into the airplane to counteract those?

THE WITNESS: The 727 I think was probably the last airplane under the Civil Aviation regulations, the CAR's. I think the 737 was probably the first airplane. And as I recall -- it's been a long time -- the airplane had to be good for any single failure and the airplane had to be tolerant of jams in the various systems and flight controls.

MR. PHILLIPS: The 737 had a failure analysis performed during certification or prior to certification. Are you familiar with that analysis?

THE WITNESS: Yes, I am.

MR. PHILLIPS: And in the case of loss of control of rudder surface, are you aware of what the failure analysis showed or what the resulting action would have been to overcome that failure?

THE WITNESS: As I recall, it indicated that if the rudder becomes inoperative, use a lateral control. And we've had a lot of discussions on the tradeoffs of using lateral versus rudder.

MR. PHILLIPS: So in the event of a fully displaced rudder, displaced to the blowdown limit, the pilot would be expected to use the lateral control system to overcome that?

THE WITNESS: That's what the failure analysis said. Yes.

MR. PHILLIPS: And I believe in that document there's also some discussion of disabling hydraulic or flight control systems related to the hydraulics. Would that also be an alternative to the runaway position or hardover position?

THE WITNESS: I think you get into a situation where that's an alternative that's possible, but you start depending upon somebody analyzing and analyzing properly and only turning off the systems when it's the right failure. To misanalyze the failure or situation that they're in and turn off the flight control systems would not be a recommended thing, I don't think.

MR. PHILLIPS: Then if I can restate what you've just said, the lateral control exists to overcome the hardover rudder position and that although it may be an alternative to disable the hydraulic system, in your opinion it wouldn't be a recommended procedure.

THE WITNESS: As I alluded to earlier, the manual reversion forces to fly the airplane without any hydraulic system are considerably higher than the standard field forces in a normal situation. It would be an unusual situation. It would be something different than guys do on a daily basis. And I think in the long run, I guess I would feel that looking at the probability of misanalyzing a system and going to manual reversion when it wasn't necessary is not a recommended thing to do.

MR. PHILLIPS: Do you have anything to add, any other statement you'd like to make or what you'd like to discuss?

THE WITNESS: As far as the control system? There is one foil that we brought that we didn't get into. There's been a lot of discussion on contamination of the valve and you alluded to it earlier.

If we can show number 12, chart number 12.

(Pause.)

There's been a lot of discussion in the investigation on this about fine particle contamination and is it a situation that we need to perhaps increase our filtration or do something else about.

If you look at a typical slide and sleeve valve, a typical slide and sleeve valve is a steel cylinder inside of a hollow -- just a rod inside of a cylinder. And these things are very, very close tolerance, very tight fit. A typical diametral clearance on a lapse slide and sleeve valve would be anywhere from 80 millionths to maybe as much or two or three thousandths of an inch. But 80 to 200 millionths is very typical.

Now that turns out, if you look at it, is like 1-1/2, maybe as much as 2 microns. Now a valve has what we call an underlap, and the underlap a space that's about 25 microns, about a thousandths of an inch, where we interconnect both sides of the cylinder. And that allows us to change what we call the flow gain in a very small part of the performance characteristics of a valve, and that gets into the servo analysis of why you want to do that.

But what it does do is it creates fundamentally an open hole and that open hole is about 25 microns wide and in a plane it would be perpendicular to the paper. It would be as wide as the metering slot. And on this particular valve, that's about 14 thousandths, as I recall. So you have a pretty sizable hole. And so these 10, 20, 30 micron pieces of material with 3,000 psi upstream, you can see quite readily that they would be pushed right through that open hole into the downstream with a minimum of 1500 psi driving them through.

We don't see that kind of small particle contamination jamming a valve or sticking a valve. What jams a valve is rust, perhaps, corrosion products. We had an airplane, an Air Force airplane once upon a time, that was serviced with water and the parts all rusted. We had to change everything out in the hydraulic system and flush it.

For a large particle -- when I say a large particle, I'm talking about something that's big enough to go into the flow passage, into the metering slot, and wedge in there and stay and not flush on through. A piece of block wire, we've had a couple of shocking bolts, things like that.

So, we have found that over many, many years that small particle contamination is not a problem with side and sleeve valves. That we need to be concerned about the large particle contaminations. And as I said before, that happens about once every 10 million hours because occasionally something is left in the package when it's manufactured or introduced during maintenance or some other -- who knows where they come from -- from time to time.

So once every 10 million hours we may get a large particle jamming a valve and that's where the dual valve comes in. If the primary would jam, the secondary would override it and perform its function.

MR. PHILLIPS: Are you aware of a dual slide concentric valve in a Boeing aircraft design or Boeing aircraft for an airplane, jamming and resulting in a loss of control or loss of function of the system?

THE WITNESS: Not losing control of the system. In each case that I'm aware of, the valve has performed precisely as it's been expected to do. Certainly if it's not expected and people don't recognize what it's supposed to do -- I've heard that the thing doesn't work, but in reality we've had like I said, a lot of shocking balls. We had one rusted part and we've given you a couple of service reports and the valve performed its function exactly as it was intended to.

MR. PHILLIPS: Would these failures be obvious to the flight crew?

THE WITNESS: I believe they would. Remember, I said the function is to dump the package, dump the pressure, depressurize the package. But in certain cases it would provide full hinge moment at that rate. And so in any case except -- well, let me put it one way. If it jammed in the extreme of travel where the surface was dead and that could be written up as rudder peddle jam is one of the ones that we had, and the reality, the valve was bypassing fluid and didn't respond. Very obvious.

In the other extreme, if it jammed in primary and neutral and it was being overridden by the secondary where you actually had performance out of the valve, you'd get full hinge moment capability at 50 percent travel and any jam in between you might get 20 percent hinge moment at 20 percent rate. And those things would be detectable in a control check.

MR. PHILLIPS: In other testimony we heard some discussion of blowdown. Could you describe what blowdown is from the systems perspective?

THE WITNESS: Blowdown is if you look at this rudder package specifically, it's designed to react in air load at a relatively low airspeed to counter an engine out. On this particular airplane it's 100 and some knots. I don't know the exact number any more. And that's how much power we put into the power control package; 3,000 psi times the area of the piston. That's how much torque can be generated on the rudder to react the air loads.

As the airspeed goes up, the air resistance goes up, obviously. And what it says is for that amount of torque that we built in, you can only deflect the rudder a limited amount so that it creates the torque that the package -- react the torque that the package can produce.

So, at 110 or 115 knots, whatever it is, you get full rudder travel at 3,000 psi differential across the pistons. At 300 knots you'd get considerably less amount of rudder to recreate that same amount of torque.

MR. PHILLIPS: Is that something that just happens in the design or is it on purpose to designed, the area the pistons control for blowdown?

THE WITNESS: On this airplane we have made the pistons as small as we possibly could to handle the engine out at low speed because if you look at the design of the body bending moment in the fin, the bigger the package is the more metal you have to put in the body for body bending loads. And so it's to our advantage to make the package as small as possible and that's what we do.

MR. PHILLIPS: And one last question on the main rudder power control unit. Is the design similar for all 737 series aircraft? Could you briefly describe the differences between the 100, 200, 300 and 400?

THE WITNESS: The 100 and 200 came out with two sets of yaw damper pistons. The 727 which is just before this airplane, required an operable yaw damper if you were flying at some altitude and speed. The 737 had two yaw dampers because the same people did the design and if you needed it once, you put it in the next airplane. And that's the best guess that the people that did the wind tunnel testing had at the time.

In flight tests, it turns out the airplane was quite stable, did not need dualization on the yaw damper for Dutch roll damping and so at some later point in time, -- I can't remember exactly when it was. I think I may have some notes.

(Pause.)

In about 1974 we took out the second yaw damper piston because it had just been going along for the ride. So at some point in time we took out the electronics and went to a single package.

So we have packages that have two yaw dampers, one of which isn't hooked up to anything. It just sits there because there's no electrical system in the airplane any more. We have later packages with a single yaw damper package. And then over a period of time we have packages with different amounts of authority.

We have 2 degrees, 4 degrees, and today we're back to 3 degrees.

MR. PHILLIPS: And who provides that main rudder power control unit to Boeing?

THE WITNESS: The main rudder power control unit is designed on Boeing paper with exception of the servo valve, which is a vendor proprietary item. And the package is procured from Parker Hannifin.

MR. PHILLIPS: And the standby rudder actuator supplier?

THE WITNESS: The standby rudder package is procured under a procurement specification. It's a vendor designed item that we buy under specification. And that's from Dowdy Aerospace, Los Angeles.

MR. PHILLIPS: I've got no further questions.

CHAIRMAN HALL: Do any of the parties have questions of this witness? Anyone other than the Boeing Corporation?

If not, Boeing, please proceed.

MR. McGREW: Thank you, Mr. Chairman.

Mr. Turner, the only question I have is are you totally satisfied that the amount of galling in the load seen at the actuator -- the standby actuator, would absolve it from any participation in the 427 event?

THE WITNESS: There's no doubt whatsoever.

MR. McGREW: Thank you, Mr. Chairman.

CHAIRMAN HALL: Thank you.

Mr. Marx?

MR. MARX: I'm interested in that last answer to the question having to do with galling. My understanding is in your testimony here, anyway, is that some yaw damper irregularities that have occurred in the past can be traced back to what you feel to be galling in the standby rudder. Is that correct?

THE WITNESS: We had one case in 1986 that had erratic yaw dampers. I believe it was -- the write-up, the only thing we found was gall packages -- gall in the fluid drain.

MR. MARX: And is it possible for the freezing of the standby rudder by galling, which may be temporary or what have you, to cause the rudder to move past the three degrees from the yaw damper input?

THE WITNESS: Past three degrees?

MR. MARX: Yes.

THE WITNESS: Just because of the yaw damper input?

MR. MARX: Well, we know that the yaw damper, based on your testimony, will be limited to plus or minus three degrees, a total of six degrees. And if you have galling that occurs in the standby unit, let's just say that we have a frozen unit up there. How far is it possible to drive the rudder?

THE WITNESS: We have done some calculations of that and you get different answers depending on what assumptions you make on spring rate; what assumptions you make on how much friction; whether the thing springs back; whether it's forced back.

What we have seen in our calculations is static offsets at -- say, for instance, the report that you have of 60 pounds where the thing is galling to the point of 60 pounds, the field and centering unit would cause that galling to break loose. It provides enough force to break that galling loose in the 2-1/2 to 3 degree, as much as perhaps 4 degrees, depending on the amount of friction in the system.

If you were to say is it conceivable that this thing could stick, the yaw damper could put in input, cause this 2 to 2-1/2 degrees offset, the airplane yaw in the other direction, the yaw damper reverse direction and get those things attitude, that could very well be. I have no way of knowing that for sure.

MR. MARX: I don't quite understand. You're saying that it can move past 3 degrees?

THE WITNESS: In a dynamic overshoot situation, I wouldn't be surprised.

MR. MARX: Well, how far past 3 degrees could it be moved?

THE WITNESS: Our simulations would indicate that a typical -- depending on the assumptions you make -- could be 4-5, maybe 6 degrees. That's my recollection. I think you have a report from 585 on that.

MR. MARX: You were also making some statements about hard and soft materials and the effect of galling. Is there anything else, such as high contact pressures that could produce galling?

THE WITNESS: Well, obviously the parts have to be rubbing against each other, but again, I'm not a metallurgist so my perception of galling is two parts that are rubbing against each other. If they are of similar hardness, if they're not lubricated, then the harder you push them together the more likely they are to gall.

MR. MARX: Well, I happen to be a metallurgist so I do know a little bit more about it. What I'm trying to get across here is that if you have two materials that come together and produce galling and galling is a result of something that can be produced by high contact stress, could that high contact stress be signifying some other problem that is occurring in the shaft and bearing?

What I'd like to do also is go a little bit into where this galling occurred on this particular shaft. Do you know whether galling occurred?

THE WITNESS: I've seen the pictures. Yes.

MR. MARX: And was it in the same location as that that occurred on Colorado Springs?

THE WITNESS: No. Colorado Springs occurred in the unlubricated part of the shaft outside of the seal, and this one occurred on the inside.

MR. MARX: On the lubricated portion, would you expect to have higher contact stresses because you are in the lubricated portion to produce galling or versus the one that occurs in the unlubricated portion?

THE WITNESS: The speed of rotation is so slow on that thing. I'm not sure that it would be a lot of difference on the things.

MR. MARX: Well, what is the speed rotation on it?

THE WITNESS: The thing moves back and forth approximately 2 degrees and it would move at -- depends on how hard you kicked the rudder peddle. Probably 30 degrees per second or something like that.

MR. MARX: This is the -- you're talking about the rotating of the shaft with respect to the bushing?

THE WITNESS: The bushing to the bearing.

MR. MARX: What's to keep a bound up from galling on the standby unit from running away or causing the main PCU to run away?

THE WITNESS: The torsional compliance in that area, if it tries to drive the system, it starts to lift the field and centering cam up out of the detended position. That loads that compliant link and that part bends, rotates, gives up. And that allows and actually puts a signal into the main rudder package to stop the motion.

MR. MARX: And this was established as a result of the investigation that was done in Colorado Springs?

THE WITNESS: No. It was really investigated thoroughly in our iron bird testing in either 1967 or 1968, which was the reason that we were able to take the shear-out mechanism out of the linkage, which was put in there for protection against that particular failure mode. The shear-out didn't work because of the compliance, so it was inherent in the system.

MR. MARX: I'm not too sure -- I didn't follow that, what you were talking about on the shear-out. Could you explain that one more time?

THE WITNESS: When we designed the airplane way back when, you may recall we said we had to be good for any single failure, including any jam, bind, valve jam, whatever, in the standby package. And we put a shear-out in there, so that one could put your feet on the rudder peddles and cut the shear out and release that from the rest of your system and regain normal control.

That shear-out wasn't needed because of the softness in the torsion link that travels between the main package and the standby package, and the torsional capability of that part negated the need for the shear-out. It simply wound up so much that we couldn't cut the shear out.

MR. MARX: During normal yaw damper operations, the yaw damper is moving back and forth to cause the rate of change movement on the main PCU, which is the primary and secondary valves.

What is the maximum rate that the yaw damper can move that rudder? I'm talking about in degrees per second.

THE WITNESS: I'd have to look it up, but O believe that it can run at about 30 or 40 degrees per second maximum rate, maximum yaw damper rate.

MR. MARX: Why can't it do the full rate travel of -- what is the normal? If the pilot input into the rudder peddles the maximum rate he could do, what would that cause in the main PCU? How fast would the rudder move?

THE WITNESS: Let me see. I haven't looked at this package this close for several months.

(Pause.)

Typically, we set the rate of augmentation systems by sizing the mod piston, the yaw damper piston, with respect to the flow rate of the transfer valve. The transfer valve gives you about three-tenths of a gallon a minute and I don't remember what the area of the mod piston is.

Relying on memory, I don't know what the area of that is. But that would say how fast the mod piston could move. The mod piston has enough stroke to certainly drive the rudder package to its maximum rate. If that area is small enough to be saturated at three-tenths of a gallon a minute, I guess it could run all the way up to maximum travel.

My recollection is it's a little less than that, maximum rate. My recollection is a little -- I may be wrong on that. It's been a long time since I looked at it.

MR. MARX: I think from what I hear from you is that you're telling me you're not actually sure but you think it could go to full maximum rate, but you're not sure. Sometimes you think it may --

THE WITNESS: Let's make an assumption it can go at 56 degrees per second.

MR. MARX: And what would be the maximum?

THE WITNESS: Then where would we go?

MR. MARX: If the maximum rate -- in other words, can we take and move the -- in the yaw damper, the question would be can the yaw damper move the secondary as far as it can move to its full travel?

THE WITNESS: The yaw damper is capable of moving the primary and secondary to the valve stops; yes, to the external valve stop. In a normal situation, there's no doubt in my mind that the yaw damper piston itself can stroke at three-tenths of an inch, roughly three-tenths of an inch. It's enough to drive both primary and secondary to the valve stops, yes, the external valve stops.

MR. MARX: And what about the internal valve, internal stops?

THE WITNESS: The only way you can drive the secondary to the internal valve stops is to have a jam of the primary to the secondary so that you have a direct load path without going through the secondary linkage.

MR. MARX: Okay. I think I'll probably ask some questions later on though when we get to some of the other people, but I was just trying to get a --

CHAIRMAN HALL: Can we -- in an attempt to follow this conversation, do you think we could put Exhibit 9-S back up there, page 7? And you could explain the operation of this yaw damper to us one more time.

THE WITNESS: Chart 7 you say? Okay.

CHAIRMAN HALL: If I understand what we're trying to do is find out how far this thing can move; right?

MR. MARX: Right. I realize that it's a very complicated subject and --

CHAIRMAN HALL: No. I don't have any problems. That's what we're here for is to get into complicated subjects. But I thought it would be helpful because I'm having difficulty following it.

MR. MARX: Well, don't feel bad at all about that.

(Laughter.)

It took me a couple of days before I got it straightened out.

THE WITNESS: There's little doubt that it's extremely complicated, and this particular picture, I might suggest we could talk for an hour and it would probably still be confusing. There's a later video coming on in Paul Cline's presentation and the video has this thing laid out in a cavia model, a 3-g type cavia model where you can actually see the motions of these internal summing levers. And it might help to get a better picture.

Just to give you an idea of what you would be seeing, could you put up the next chart, chart number 8?

CHAIRMAN HALL: What part of that limits the yaw damper's movement?

THE WITNESS: See the area that says -- up near the top of the page, it says Yaw Damper Actuator?

CHAIRMAN HALL: Right.

THE WITNESS: That's a steel cylinder that moves inside of a bore, and that's the yaw damper actuator. And it's a spring cage to a neutral position and -- why don't we try the next chart, and this will give you an idea of what you're going to see in a video that's actually a moving video.

As you can see, there's a multitude of parts there. The upper piston, you can see that that upper piston has a limited stroke. It can only move within the bore that's available to it. And that's the yaw damper actuator and while it's going to be awfully tough to see in this two-dimensional picture, when you get to the moving simulation, what you can see is that the yaw damper piston servo system, if you put a command, everything starts to happen. But if you break it down one piece, you put an input in and then this happens and then this happens. And take it one step at a time.

You can see that the yaw damper piston, if it moves, it will move what we call the internal summing links. And the internal summing links would pivot about Point B. Those would move the servo valve and the servo valve at that point would be porting fluid to one side or the other of the main power piston.

And the main power piston, this big thing up on top that says piston, would then respond and would move. When that moves, the bottom part of the summing lever is fixed. It's connected to the pilot's rudder peddle, so it doesn't move. And what happens then is as the top end of that big lever moves, it moves a thing called a valve crank, which is like -- the external summing link, I guess, is the way it's labeled, which drives the input crank that rotates and literally moves Point B over. And those motions add up to read all the valves, so that the valve goes back to neutral and the piston stops moving.

Within that complicated linkage train, the piston is obligated to -- output piston is obligated to move in a direct proportion to the amount of stroke of the yaw damper and the linkage ratios of all these summing levers.

CHAIRMAN HALL: The law damper moves without the pilot? Doesn't require the pilot's input; right?

THE WITNESS: That's right.

CHAIRMAN HALL: This is an electrical --

THE WITNESS: This is a series mode. And within the authority of the yaw damper actuator it will move. And the input point will not move for those three degrees.

CHAIRMAN HALL: And it's basically moving all the time in flight or a lot, part of the time?

THE WITNESS: It tends to move -- cycle, at the natural Dutch roll frequency of the airplane.

CHAIRMAN HALL: And what is the life of a unit like that?

THE WITNESS: The whole power control package being a hydraulic device with teflon and rubber seals in it, 20,000 hours is a pretty good life on a piece of hardware like this.

Generally, the moving parts, the metal parts, don't wear out as rapidly as the seals, the soft parts. And so the typical thing you do on hydraulic equipment is monitor the leakage, and when it starts to leaking quite a bit, whatever the airline elects to put as their criteria -- and we've got some recommendations for that. When it gets to leaking to the point they want to change it, then they schedule maintenance and change it.

Now, we put in teflon cap strips on the seals so that when it starts to leak, it starts to dribble, and then more and then more and more, rather than the other failure mode of a pure rubber seal is it's real dry and all of a sudden it goes -- atchoo.

The long life seals that start to dribble and dribble and dribble allows a maintenance operation to schedule maintenance on it.

CHAIRMAN HALL: I'm sorry, Mike. Proceed ahead. I didn't mean to butt in, but --

MR. MARX: I think that maybe some of the other technical questions we could ask to the other witnesses that come in. I was just trying to get your feel for it because of the amount of experience that you have with these units.

If you could just give me some ideas as to why you answered the question that the Boeing representative asked you about the galling. I think the question was to the effect that this galling could have had absolutely nothing to do with the movement of the rudder. To that extent, could you go a little bit further into that?

THE WITNESS: The testimony that we've heard so far indicates a rudder motion that comes in roughly 5 degrees per second to a full blowdown position. If it were the rudder, and that's what people have been discussing, bringing something in at a particular rate like that is not the characteristic at all of having a gall package. A gall package, the stroke would be considerably less. The field and centering unit would break it out at some small amount of rudder.

As a matter of fact, this one actually measured half a pound, less than half a pound. And at less than a half a pound, that's way, way -- that's smaller than what the field and centering unit can handle.

And in any case, the field and centering unit alone, with no input from the rudder peddles at all, no corrective action at all, the field and centering unit would prevent this thing from every going -- what did we have? 16-18 degrees? Whatever the chart showed. There's too much compliance in the system for that.

And this thing went over at a relatively constant rate, an average rate of 2-1/2 to 5 degrees. That's just not the characteristic that we have seen or would expect to see.

MR. MARX: So you wouldn't be able to get the rate of 2-1/2 to 5 degrees with a frozen bearing to the shaft? Is that what you're saying?

THE WITNESS: You couldn't get it all the way to the 16 degrees.

MR. MARX: No, but how about the rate, 2-1/2 to 5 degrees?

THE WITNESS: One would have to start to speculate some kind of a thing where -- gee, I don't know what you'd do. Assume that it wasn't stuck and all of a sudden it welded solid at some particular position. That would be pure speculation.

MR. MARX: Are you aware that in galling situations you can actually have a very large force at one time and then a very small force resulting from the breakaway or that this connection of the transferred metal or the T welding of the metal as it breaks away? Are you aware that this force, rotational forces, can go down?

THE WITNESS: I'm aware of that.

MR. MARX: So the one half pound that was measured after the accident may not be representative of the position in which it was actually -- the metal was transferred onto. Is that correct?

THE WITNESS: I think that's speculation to draw that conclusion in my opinion.

MR. MARX: Okay. Let's put it this way. Have we done any galling tests at all on parts in the past as a result of Colorado Springs?

THE WITNESS: Yes. In participation with the Systems Group, they asked us to set up a test, and we manufactured some special parts and created galling, and we'd create galling on a number of samples. What we were attempting to do was to try to duplicate the kind of galling that we saw in Colorado Springs and also match that with the part that we had from 1986 where we knew what the galling load was, which was 57 pounds on that particular part in 1986.

We ran probably six or eight samples and recorded the breakout force, the running torque. And yes, we saw that it tended to be a function of how rapid you moved it. If you'd run it at a fairly slow rate and then you made some larger inputs through the rudder peddle, you had a tendency to get a higher force at that particular point in time, so it's not constant.

MR. MARX: It's not constant.

THE WITNESS: But we didn't see anything in any of our testing where it was very, very low and then suddenly got very, very high and then suddenly went down to nothing. What we saw was if it was on a test part -- and we took one of these test parts and ran it and ran it and ran it until it was solid, as solid as we could get it, like 120 pounds, it had a tendency to go stick slip, but not from zero to 120 pounds. It was 140 to -- you know, it varied but it didn't go from zero to a big number. That's what our test indications were.

MR. MARX: Not from zero. I'm talking about from a large number down to a very low number where you have actual sticking of the parts and then that sticking breaks loose and you go down to a low number.

THE WITNESS: We didn't see that in the test program that we ran for you at all.

MR. MARX: Okay. I don't have the data here in front of me either, so I just wondered what you recalled from that test.

THE WITNESS: It changed in value, but we didn't see gross changes of the kind you're talking about. No.

MR. MARX: I have no further questions.

CHAIRMAN HALL: Mr. Clark?

MR. CLARK: I have no questions.

CHAIRMAN HALL: Mr. Schleede?

MR. SCHLEEDE: Just a couple areas, Mr. Turner.

In the maintenance records for this accident airplane, Flight 427, the main rudder PCU was replaced in January of 1993. And I'm not sure if this is in your area of responsibility or expertise, but there was a non-routine work card written for the bolt that attaches the PCU to the rudder, that it found to have, and it quotes, "a slight step worn in it," and the bolt was replaced and shipped back with the PCU, which had been leaking.

First of all, are you aware of that information?

THE WITNESS: I have read your exhibit. That's the only thing that I personally had to do with it.

MR. SCHLEEDE: Do you have any knowledge or experience regarding this type of wear on that particular bolt?

THE WITNESS: Well, it's the main pin that went through the main piston into the rudder. What happens if that bolt wears, sometimes under load the pin will rotate in the bushing rather than rotate in the bearing, particularly if you're flying at high altitude and the temperatures are very low and the grease gets stiff in the bearing. And as the pin rotates in the bushing or it could even rotate in the inner recess of the bearing, depending on the fit, those pins wear from time to time, and what you get is backlash. And, you know, in a C check or D check, there's a backlash check.

MR. SCHLEEDE: So is this something that you would become aware of in the course of your responsibilities?

THE WITNESS: I would have, had I still been in the Sustaining Group. It's the kind of thing that if it's reported, and of course there's a series of legal requirements on reporting. If it's reported, it would come into our Service Group. Our Service Group would monitor those reports and get with the appropriate Sustaining people and we'd take action where necessary.

How that process works, I think Mr. Johnson will go over that in a lot of detail. But it's the kind of thing that if we saw very many cases of it, would know about it.

MR. SCHLEEDE: Well, you are aware of past instances of that?

THE WITNESS: I don't have any -- I can't recall of any other than this particular one, but I'm not a bit surprised. It's just another bolt and another wear part.

MR. SCHLEEDE: Would it be possible to point out the location where we're talking about on there? Is it on that diagram?

THE WITNESS: I think it's a small picture but -- put the other one back up, please.

If you can hit the main rudder control package rod end where it attaches to the -- there you go.

MR. SCHLEEDE: Okay. We're on Exhibit 9-S, page 6.

THE WITNESS: When I read that report, I believe that's the bolt they were talking about. I didn't spend a lot of time reading the report, but I think that's what they were talking about.

MR. SCHLEEDE: I was just curious whether there was -- because in fact it was found on this particular aircraft, is there anything within the main PCU mechanism or any of this other bushrods and so forth that could generate forces to that bolt?

THE WITNESS: That bolt takes the full load of the rudder power going into the rudder, so it's loaded every time that you fly the airplane multiple times. And during the certification of the airplane, during the testing, we go in there and put undersized bolts in and see whether there's symmetric backlash that we can get phenomenon on the flutter, which we heard about earlier.

So we go into the maintenance manual and put wear and rework limits on that bolt, and so that's a point that we test to see how much backlash can we have there without creating a condition we're concerned about. We put that in the maintenance manual and that's one of the inspection points.

MR. SCHLEEDE: What kind of condition would you be concerned about if there was backlash?

THE WITNESS: Flutter. If it got too great, you'd have potential for flutter. And it would be plenty times more backlash than what's allowed in wear and rework tolerance area of the maintenance manual.

MR. SCHLEEDE: I know you're probably getting tired of talking about standby rudder actuator. If the standby rudder actuator is frozen solid, and I know it wasn't in this accident with 427, but if it's frozen for any reason, galling or the servo valve is corroded and frozen, what effect does that have on the operation of the rudder system?

THE WITNESS: You're saying a hypothetical, if you were to put a clamp on there and you couldn't move it?

MR. SCHLEEDE: I'm aware of one particular incident, a recent one, which a servo within the main PCU was frozen from corrosion. Now if it's frozen or galled up to a significant value, what is the resultant reaction to this rudder system?

THE WITNESS: On that particular one that you're talking about, I believe it's the one that was rusted and the valve had broken off. That's a case there where during -- undoubtedly, during a control check, the housing didn't move with respect to the pilot's input command; broke the ball off. It takes about -- you know, we broke one of those in the 585 investigation and it took -- I think it took 75 pounds at the input crank to snap that ball off.

So what you would get is this thing would start to backdrive, if you want to call it that, and then the field and centering unit or the pilot's command would create enough load to wind up the input crank or the torque tube and the rudder would offset some small amount. Depends on whether it was jammed directly at neutral or some offset amount. It depends on how far it would go.

MR. SCHLEEDE: If you had it in that condition and had a step input on the yaw damper, what would be the result?

THE WITNESS: That's where we were talking before of how far it would go. You'd get an erratic yaw damper.

MR. SCHLEEDE: Okay. But --

THE WITNESS: See, the yaw damper, the

control laws, the electric control laws are expecting if the black box put in half a degree of rudder, it's expecting to get the airplane response out of a half a degree of rudder. If it gets more or gets less, then it tries to correct for that electronically, and so the electrons try to do something different, try to correct for something that they can't handle. And it sits there and doesn't cycle at its normal rate. It goes erratic.

MR. SCHLEEDE: Okay. I think one more in that area. If the standby is frozen for whatever reason or severely galled up and there's for some other reason a loss of A and B system in flight, is the airplane controllable in that condition?

THE WITNESS: That's a triple failure and the answer, the short answer is that the airplane is not capable of handling any number of triple failures, and this is one of them.

Now, to prevent that from happening, the hydraulic systems themselves are quite reliable. Having a double failure is a rare event in itself, and we go check the standby system at every C check, which is an appropriate time interval to go check for those latent failures that you're talking about.

In that respect, this airplane would meet the same criteria as a brand new 777 for two latent failures or two active failures plus one latent failure. It would be well past that. Extremely improbable.

MR. SCHLEEDE: In this case your latent failure would be the standby --

THE WITNESS: That's correct. With the recommendation that is a C check. And of course that checks having a disconnect or valve jam or welding or any number of single failures in a single system.

MR. SCHLEEDE: Mr. Turner, have you learned anything in your role in the investigation of this accident or the Colorado Springs investigations that gives you concern for any changes that need to be made to the rudder system on the 737?

THE WITNESS: One change that we are considering is, since there's been a lot of publicity and we have seen the 427 going, we did make a change to that bushing. Increased the clearance. And what we now see is the galling was outside. It's now inside. And we've got at least this one case of it that I'm aware of.

We've been taking a look at what it might take to make another change to that area. And exactly what the change would be, the people involved in the design of it will all talk about.

MR. SCHLEEDE: Okay. Well, since you raised that, are you aware that the NTSB made recommendations following the Colorado Springs investigation for periodic check of the standby rudder actuator input arm to detect binding?

THE WITNESS: Yes. I've read the proposed AD Note that was put out.

MR. SCHLEEDE: And there was a proposed AD note which was withdrawn. Were you involved in the discussions on the decisionmaking to withdraw that notice of proposed rulemaking?

THE WITNESS: Not directly any discussions with the FAA as to -- that it should or should not be an AD Note. What we did was sit down and discuss the ramifications in the failure modes and created the data to allow the FAA to make that recommendation to withdraw it. Which that data was apparently passed on to the NTSB because there's a letter in your file that concurred with that withdrawal.

MR. SCHLEEDE: You mentioned the discussions about those changes. Are there any other changes that you're thinking about or working on?

THE WITNESS: I can't think of anything that we would do to this system.

MR. SCHLEEDE: Thank you very much, Mr. Turner.

CHAIRMAN HALL: Mr. Laynor?

MR. LAYNOR: Mr. Turner, at the risk of belaboring a point, just a couple.

In the yaw damper actuating mechanism, are you aware of any failures at all to the walking beam or the summing levers or anything that can result in a primary servo valve signal?

THE WITNESS: We did find a package that came back from one of the airlines that had a summing lever that was not machined properly and it didn't stop where it was supposed to stop on the external valve stop and caused the valve to stroke further than we'd intended for it to, yes.

As far as I know, that's the only one of those that's ever been found.

MR. LAYNOR: But nothing that would explain a jam of any kind, a failure of the valve to null?

THE WITNESS: Repeat that again. I'm not sure --

MR. LAYNOR: Any failures because, as I understand that one, that would not prevent the valve from nulling the main servo valve. Is there any failures in that mechanism that would produce a continuously moving rudder to the hardover position?

THE WITNESS: Not sure what failures you might be referring to. If you're --

MR. LAYNOR: Well, I'm talking --

THE WITNESS: If we speculate that there could be some additional parts out there that are mis-machined, one could speculate that, I guess.

MR. LAYNOR: I'm just talking about known failures to your knowledge that may or may not have ever occurred to the walking beam or the summing levers or any of that mechanism, any of the freezing of any of the pivot points or anything that would explain a continuously moving rudder.

You're not aware of any?

THE WITNESS: The only one that I'm aware of in that mechanism is the one we just spoke of that was mis-machined.

MR. LAYNOR: And getting back to the possibility of a jammed either primary or secondary servo valve spool, is there any test conducted to determine what the maximum pressure differential that can be developed in any single jam?

THE WITNESS: We didn't put a limit on this particular 737 rudder valve on the drawings. There's been some testing done. There's been a tolerance study run. Those test results will probably be examined pretty detailed in later testimony.

MR. LAYNOR: Have you personally looked at any of the hardware from the accident aircraft, 427, the summing lever mechanisms and anything to determine whether you saw any anomalies?

THE WITNESS: I haven't personally looked at them. Paul Cline is the fellow that's done the lion's share of that.

MR. LAYNOR: The only other question to belabor the standby input crank arm a little bit. I was of the understanding that there was an iron bird type of test to determine the compliance in the torque tube and the levers as such. Was I under a mis--

THE WITNESS: No. I referred to it as the more formal name of the Flight Control Systems Test Rig. That's our iron bird.

MR. LAYNOR: But early in your testimony when you were discussing that in response to Mr. Phillips, you said that it was done by analysis and looking at the elasticity of the parts. Was there actually a test conducted to verify how much force that the centering spring would have to exert to bring the valve back to null?

THE WITNESS: At the time of 585 when I was involved in looking at this, the flight controls test rig for the 737 had long since gone away. We didn't have the capability of going out and doing additional testing. There was some testing done in 1967-68. I can't tell you exactly what all went on back there. I'd have to go look it up in the files.

But no, we did not, when we reviewed this a couple of years ago, have the facilities to go do that kind of testing.

So, at that point, that part of it was done by analysis.

MR. LAYNOR: Okay. Do you know of any failures, any type of malfunctions at all in your knowledge of the history of the 737 that have resulted in a rudder hardover?

THE WITNESS: There was one case where the airplane on approach had a jammed valve at the steel ball. I can't remember which airplane it was without looking it up. And, of course, if you have small residual pressure even 100 psi on the ground, the surface will move to its extreme of travel.

So, that particular airplane had a jammed valve. The secondary did it's job and at slow airspeed, at touchdown, the rudder went to its extreme of travel. The write-up said at 100 knots. Not an instrumented airplane. You can't guarantee the validity of that.

It did exactly what it was supposed to do.

MR. LAYNOR: Okay. So that was the pressure differential we were talking about earlier without much hinge moment that caused that to move? Is that correct?

THE WITNESS: That's correct.

MR. LAYNOR: Okay. Thank you, Mr. Turner. That's all.

CHAIRMAN HALL: Mr. Turner, first, again, let me thank you for your assistance to the Board and your patience in this testimony this afternoon. I have a few questions, however, and I hope they will be -- by nature they will be less complicated than the ones that you got from Mr. Marx.

But is the rudder system that was on the flight, the USAir 427, essentially the same rudder that was on the Colorado Springs flight?

THE WITNESS: It's the same rudder system with very minor detail differences on every Boeing 737 airplane and every model.

CHAIRMAN HALL: Were there any changes then or what were the minor modifications that were made between the Colorado Springs and the USAir accidents?

THE WITNESS: Flight 585 was a dash 200, I believe, and this airplane is a dash 300. If there was a change, it would have been in the yaw damper authority; 2 versus 3 degrees or some change like that, if there was a change.

CHAIRMAN HALL: Galling, I gather, is related primarily to wear. Is that correct?

THE WITNESS: Well, my definition of wear is you rub the two pieces together and they both disappear. Galling would be where they tend to stick together.

CHAIRMAN HALL: And referring to Exhibit 9-M, which is a letter from the FAA to then Chairman of the National Transportation Safety Board on August 5th of 1993, which is pages 17 and 18, and I'll read it. It says, "Since the issuance of this NPRM rulemaking, the FAA -- it's late.

"Since the issuance of this NPRM, the FAA has reevaluated the design of the rudder control system on the model 727 and 737 series airplanes and has determined that the flight crew would be capable of detecting the galling condition by (1) increased forced necessary to move the rudder peddle; (2) erratic nose gear steering with the yaw damper engaged; (3) rudder yaw damper kickback or yaw damper backdrives on the rudder peddles during flight; and (4) erratic operations of the rudder yaw damper or erratic rudder oscillations with the yaw damper engaged. None of these indications of galling represents a safety hazard."

Number one, do you agree with the statement that flight crews would be able to detect galling by those four methods; and secondly, do you agree that none of those indications of galling represent a safety hazard?

THE WITNESS: We had at least one case where the nut backed off. And when the nut backed off, the package performed quite some time. We think it was about two years in a perfectly normal fashion and would have continued to operate until the seal wore out and started to leak hydraulic fluid.

So if you were to say is this 100 percent detectable by these four methods? There's at least one case where, no, it just unscrewed and cured itself operationally and continued on down the road. Whether if you go on and say these phenomenon that are described here, are they extreme safety issues? The answer is the magnitude of all of these phenomenon are readily controlled by the flight crew and that's the basis for the statement.

CHAIRMAN HALL: Do you know based on this -- and I guess I'll have to ask somebody probably with the FAA -- what was done in terms of notifying the airlines and flight crew so that they would know to be able to detect galling?

THE WITNESS: I can't answer that.

CHAIRMAN HALL: Okay. I've been very impressed with the amount of time that everyone has put into both this accident and the Colorado Springs accident. Was any additional failure analysis done in terms of the rudder system between those two accidents and did you come up with anything that you all felt needed to be done as a result of that Colorado Springs accident to that rudder?

THE WITNESS: I guess in answer to that is that we continuously look at and monitor the system for failures, look at things that are potential improvements. And no, we did not come up with specific changes that we wanted to do to the rudder system as a result of 585.

CHAIRMAN HALL: But you mentioned you may be coming up, as a result of this situation, with a recommendation. You're not exactly sure what that might be. Is there any type of time frame?

I know there's other work to be continued as part of this investigation. Do you feel like that there is anything additional that you need to do, any other tests, failure analysis or any other technical things that need to be done in this regard?

THE WITNESS: Not in the areas that I'm responsible for, no.

CHAIRMAN HALL: Very well. Again, let me thank you for the -- I think you've been up here over two hours. You have been very responsive and I appreciate it very, very much, as I'm sure the rest of the panel does.

If there are no other questions, you are excused, sir. Thank you very much, again.

(Witness excused.)

CHAIRMAN HALL: It is 5:11. We will convene for one more witness today and reconvene at 5:30.

Personally, I want everyone to know that I was opposed to having one more witness, but Mr. Haueter insisted that we have one more witness today. And therefore, those of you who are patient and want to continue to stay with us, we'll see you back here at 5:30.

(Whereupon, a recess was taken.)

CHAIRMAN HALL: If we could begin to reassemble, those who would like to join us for the late session.

We'll reconvene the hearing and ask Mr. Shih Sheng to please approach as the next witness.

Mr. Sheng is a Rudder PCU, Power Control Unit, Design Engineer with the Parker Hannifin Corporation in Irvine, California.

(Witness testimony continues on the next page.)

SHIH YUNG SHENG, RUDDER PCU DESIGN ENGINEER, PARKER
HANNIFIN CORPORATION, IRVINE, CALIFORNIA

(Whereupon,

SHIH YUNG SHENG,

was called as a witness by and on behalf of the NTSB, and, after having been duly sworn, wa examined and testified on his oath as follows:)

CHAIRMAN HALL: Mr. Schleede, if you would begin the questioning.

MR. SCHLEEDE: Give us your full name, Mr. Sheng?

THE WITNESS: Yung Sheng.

CHAIRMAN HALL: Would you please say that again, sir. I'm sorry. The microphone was not on.

THE WITNESS: My name is Yung Sheng.

MR. SCHLEEDE: Would you give us a brief description of your background that qualifies you for your position at Parker Hannifin?

THE WITNESS: I'm working for Parker Hannifin with the Control System Division. My background, I have a master of mechanical engineering degree from UC-

Berkeley.

MR. SCHLEEDE: How long have you worked for Parker Hannifin?

THE WITNESS: Thirty-one years.

MR. SCHLEEDE: Thank you. Mr. Phillips will proceed.

MR. PHILLIPS: Mr. Sheng, I appreciate your sticking with us here.

Just a few questions. First of all, I guess in our introduction we call you a Rudder PCU Design Engineer. That's probably not quite accurate. What do you do for Parker in your day-to-day business?

THE WITNESS: When I started as a young engineer, I joined design teams working on all different PCU designs, but currently my position is senior member of Technical Staff. I provide all technical support to different projects within our division.

MR. PHILLIPS: So you act as an advisor to other engineering groups within Parker on several different actuator packages?

THE WITNESS: Yes. I just help them.

MR. PHILLIPS: Just help them out.

You're aware -- I guess you should ask, does Parker manufacture the main rudder power control unit for the 737 aircraft?

THE WITNESS: Yes.

MR. PHILLIPS: What other units do they manufacture for the 737?

THE WITNESS: The aileron and the elevator control units.

MR. PHILLIPS: Aileron and elevator control units. Okay.

Parker also manufacturers actuators and components for several other aircraft that you've worked on. Could you just give me a brief summary of the other kinds of packages you work on and the aircraft that they're used on?

THE WITNESS: Quite a few. First, 707 rudder, then some '27 rudders and elevators, and 747 inboard elevator, outboard elevator. On the SP, 747-SP, in addition to the elevator, the rudders also. Then on the 747-400, the inboard elevator, outboard elevator, both rudders with the control model.

That is the Boeing hardware.

MR. PHILLIPS: Okay.

THE WITNESS: You want another list?

MR. PHILLIPS: Well, we don't really need the list of each component, but what other aircraft manufacturers do you make components for?

THE WITNESS: The aircraft?

MR. PHILLIPS: Just the company, not the manufacturers. Not the particular airplanes, but the --

THE WITNESS: DC-10, the whole controls; in the 11, the stabilizer. The Gulf Stream-2, all the controls. Quite a few.

Now, military parts, we have C-5's, all controls. S-38, all controls. Helicopters, like the Black Hawk, all controls; Apache, all controls. It's a long list.

MR. PHILLIPS: Yes. That's obvious.

In some reporting concerning this accident, the USAir 427 accident, there was some reporting of a C-141, I believe, actuator package. And the reference was made that that was a Parker unit.

To your knowledge, does Parker manufacture a rudder power control unit for the C-141 airplane?

THE WITNESS: It's not my knowledge, but I don't know which one you're talking about. C-130.

MR. PHILLIPS: You make a C-130 package?

THE WITNESS: No. I'm sorry. This is the recent accident?

MR. PHILLIPS: No. This was a report in the media concerning a rudder package that Parker -- supposedly Parker manufactured that was installed in the C-141.

THE WITNESS: I don't have the knowledge of that.

MR. PHILLIPS: From your initial testimony, it's obvious that Parker makes a lot of components. How do they make a component? What starts a component being made a Parker?

THE WITNESS: Okay. When customer need a new PCU, they create what we call specification. Some of the customers call procurement specification and we call spec. Then we prepare a proposal design and propose to the customer.

Normally it's open bid. And sometimes our customer just give us the job. But anyway, after we receive the job and create a design, we will meet the customer specification requirements.

MR. PHILLIPS: And in this specification requirement, what kinds of things are you given to work with? Are you given drawings to manufacture the parts? Are you given just design criteria that you try to meet at the end?

THE WITNESS: Commercial designs, normally we receive a schematic already that tells you how the system looks like. And they give you an envelope to tell you how much space they've got. And they give us bench guidelines and requirements, so you design and calculate to these requirements.

MR. PHILLIPS: When you meet the requirements, you create a designed for specification, does Parker have control of the engineering that defines the components being manufactured? In other words, is it Parker's decision that certain components are used, certain materials are used? Exactly how does that happen?

THE WITNESS: The specification defines the performance and certain material restrictions. We have some variation we can take to try to meet the performance requirement.

MR. PHILLIPS: Do the manufacturers who generate the specification to Parker, do they participate in the design of the package if there are specification changes?

THE WITNESS: They will design review our design and normally there's a PDR, we call primary design review. Then follows a CDR, critical design review. So the customer has to approve our design. Some of the customers even approve our detailed design.

MR. PHILLIPS: I see. Once the package is designed and approved and goes into service with the airlines, what's Parker's interaction then with both the manufacturer and the airlines?

THE WITNESS: That part I'm not too familiar with it. I'm in the design section. This would be in the service section.

MR. PHILLIPS: I see. So you're more involved with the specific design of the new specification and a package before it goes into service?

THE WITNESS: Yes.

MR. PHILLIPS: Have you been involved with the Colorado Springs investigation or the Pittsburgh accident investigation?

THE WITNESS: One day when Mr. Steve Weik was not available, so they call me to support the investigation. So I was there.

MR. PHILLIPS: That was the day everyone got sick?

THE WITNESS: Yes.

MR. PHILLIPS: I guess we don't need to go into that. So you came in as an advisor to Mr. Weik --

THE WITNESS: That's right.

MR. PHILLIPS: -- because he was out sick that day?

THE WITNESS: Yes.

MR. PHILLIPS: What's been your involvement over the years at Parker in the design of the 737 main rudder PCU?

THE WITNESS: The 737 design, I just work on the linkage, you know, all the linkage designs were made by me.

MR. PHILLIPS: And the linkages are the -- could you tell us what they are?

THE WITNESS: All the moving parts.

MR. PHILLIPS: All the moving parts?

THE WITNESS: All the moving linkages you saw on Bernie's presentation.

MR. PHILLIPS: Okay. Should we throw the viewgraph up just to show what we're talking about? I see a motion that way. I think one more flip -- and one more. There we go.

THE WITNESS: Within this picture, only the main control valve and the ball piston and the main piston. That all belongs to the linkage. The rest of the unit in the picture -- the rest of it belongs to the linkage system and that was designed by me.

MR. PHILLIPS: So we're looking at some of your original design there?

THE WITNESS: Yes.

MR. PHILLIPS: Have any of those parts ever been used on another component manufactured by Parker?

THE WITNESS: No.

MR. PHILLIPS: They were unique to this unit, this package?

THE WITNESS: Yes. You're right.

MR. PHILLIPS: When you design linkages and components like that, what kind of criteria do you use for knowing how to design them?

THE WITNESS: For linkage design, first you have to know the input geometry and also you have to know the output geometry. How much the pilot input to give how much the actual output. You have to know that geometry.

Then you have to know the autodynamics, so you design the linkage to provide the velocity output of the actuator, which meets the dynamic requirements. It involves quite a bit of linkage designs; geometry, motion, through the whole range. It's very complicated.

MR. PHILLIPS: Yes. And are you involved in selecting the materials for the linkages?

THE WITNESS: Yes.

MR. PHILLIPS: The testing that's done after the design is complete to assure that the materials meet those specifications, do you control that testing? Are you involved in that?

THE WITNESS: We call qualification test. I help our qualification department to run the test.

MR. PHILLIPS: So the unit is manufactured and then it's tested to a test for performance. In that process, is the manufacturer still involved in identifying and developing the qualification test plan or procedures?

THE WITNESS: Yes.

MR. PHILLIPS: Would you be prepared or is it in your experience to talk about the effects of contamination or particles getting into control valves?

THE WITNESS: I'm not an expert in that area, but we have a filter in front of the inlet. So normally the fluid is pretty clean when we reach the components.

MR. PHILLIPS: In the service department or the support of the PCU as it's in service with the airlines, although it's not your area, are there ways that information that comes back from the airlines can get back to you so that you know when your design needs to be modified or if it needs to be improved?

THE WITNESS: Normally, they were not sent to me. Unless I request them, they will give it to me.

MR. PHILLIPS: If you requested it, they would give it to you?

THE WITNESS: Oh, yes.

MR. PHILLIPS: Otherwise it's in other people's hands to review?

THE WITNESS: That's right.

MR. PHILLIPS: In your opinion, is this main rudder power control unit used on the 737, is it a unique design? Is it different than any other design out there?

THE WITNESS: The actual design principle, basically is very common to all actuator designs. The principle is very common. It's just like your car's power steering. The power steering has a sole valve, a linkage, just like that.

So the application for this particular unit to just fit the 737.

MR. PHILLIPS: Has a unit like this been used on any other airplane after the 737?

THE WITNESS: Not this particular unit.

MR. PHILLIPS: Not this particular unit.

My advisors here are asking me to ask you to maybe discuss a little bit the function of the dual spools in the servo control valve. Could you just generally give us an overview of in a control valve why we have dual concentric spools?

THE WITNESS: Because the design requirement, as I remember, it says there's no one single failure. It endangers the rudder system. So Mr. Turner already explained to you if the primary jams or the secondary, then the secondary can reverse the direction and will solve the actuator.

MR. PHILLIPS: Is this dual concentric control valve used on other Parker PCU's?

THE WITNESS: Yes.

MR. PHILLIPS: And which ones are those?

THE WITNESS: The first one is 727 elevator. Then it's 707 rudder, then 737 rudder. That's this one. The next one is the 747 inboard elevator.

As I remember the 737 A and E, the aileron and elevator unit also got the dual concentric valve.

MR. PHILLIPS: After the Colorado Springs accident investigation the NTSB wrote a safety recommendation asking the FAA to review and Boeing to review dual concentric servo valve designs manufactured by Parker in regards to failure conditions.

Were you involved in that review or were you aware that that recommendation had been made and a review was being conducted?

THE WITNESS: I studied the design and helped to modify the design. But as far as the whole review, I participated in that.

MR. PHILLIPS: You did participate in that?

THE WITNESS: Yes.

MR. PHILLIPS: And you also were involved in modifying the design of the 737 PCU after the Colorado Springs event?

THE WITNESS: Yes. That's correct.

MR. PHILLIPS: In the original -- in the list that you just gave me of other dual concentric valves manufactured by Parker, are there any significant differences in specifications or tolerances, clearances and things in those valves or are they all generally the same?

THE WITNESS: Generally, they're all same.

MR. PHILLIPS: Do you have anything else you'd like to add, any other area that I haven't covered you'd like to discuss?

THE WITNESS: No.

MR. PHILLIPS: Thank you very much. I have no further questions.

CHAIRMAN HALL: Do the parties have questions of this witness?

(No response.)

I see no hands.

Mr. Marx?

MR. MARX: I just have a few quick questions.

The linkage that you design on the 737, is that a redundant linkage or each one of those --

THE WITNESS: Yes.

MR. MARX: -- links themselves, if one breaks -- I mean, would you just explain the design?

THE WITNESS: They're all redundant. They all have dual load paths.

MR. MARX: So each one of the individual components have a dual or like two components in one. Is that correct?

THE WITNESS: Yes. Okay. The first piece is the external summing lever. It's actually got four pieces bound together. The external summing lever. In the picture you don't see the actual four pieces bound together. In the next one you have the link. You have two pieces bond against each other. They're riveted together.

MR. MARX: And each one of those individual pieces that are bonded together can carry the full load of the link?

THE WITNESS: Yes. That's right. And the shaft, actually you've got two shafts, one inside each other -- one inside the other.

MR. MARX: In the linkage itself, is this all an open air or to the ambient environment?

THE WITNESS: External linkage; yes.

MR. MARX: And what about the internal linkage?

THE WITNESS: It's in the linkage cavity, which is the return fluid.

MR. MARX: Okay. The linkage cavity would be that which would have the summing levers in them?

THE WITNESS: The internal summing levers.

MR. MARX: Is there any place in that linkage that can cause or can be a source of binding or sticking in the linkage itself that can cause some type of jam?

THE WITNESS: I'm not aware of that.

MR. MARX: Is there any place in the linkage that it comes close to other components in which something could get stuck in between that and another spot and cause a jam?

THE WITNESS: Since the linkage cavity is isolated, the foreign particle would not get into that, so there's no foreign object that will cause the jamming.

MR. MARX: Okay. I have no further questions.

CHAIRMAN HALL: Mr. Clark?

MR. CLARK: You described a number of packages that Parker designs that go on various airplanes and I lost track. Do you build the packages that are used on the rudder systems on the 727?

THE WITNESS: Yes.

MR. CLARK: So there's two systems for each airplane in that design?

THE WITNESS: Two rudders. One upper rudder; one lower rudder.

MR. CLARK: Is that rudder system similar to the rudder system on the 737?

THE WITNESS: No.

MR. CLARK: It's not a derivative or the body of the actuator the same part number or a similar part number?

THE WITNESS: The valve is completely different.

MR. CLARK: The valve is the servo valve?

THE WITNESS: The main control valve.

MR. CLARK: The main control valve is completely different.

THE WITNESS: Completely different. It's a single slide. It's not a valve in a valve.

MR. CLARK: Is the actuator itself, the

piston, are they similar or -- similar in design although they may be different in size or there may be differences that create a different part number?

THE WITNESS: It's a completely different part number. None of them can interchange.

MR. CLARK: If you suspected a design problem, for example, in the 737 package, would that lead you to look for similarities in the 727 package then?

THE WITNESS: You're talking the 727 rudder?

MR. CLARK: Yes.

THE WITNESS: I'm not aware of any problem on that.

MR. CLARK: If you found -- I guess I'm asking for the similarities of design and you're indicating they are quite dissimilar.

THE WITNESS: Not same.

MR. CLARK: Okay. Not the same at all. Okay. Thank you.

THE WITNESS: Not similar.

MR. CLARK: You also said that the dual concentric valve is used on several different designs.

Are all of those dual concentric valves a derivative of the one that is on the 737 or are they similar or similar part numbers?

THE WITNESS: The principle's the same.

MR. CLARK: The principle's the same but they're different designs?

THE WITNESS: The design is different.

MR. CLARK: Every one of those others are completely different then?

THE WITNESS: The 737 and 727 a little close, but still not same.

MR. CLARK: It's hard to quantify what is a little close. Does the external package of the valve look the same or does it start with the same -- similar parts and give them different part numbers for slight differences in size?

THE WITNESS: The main difference in the 727 there is no external linkage stop because there is no yaw damper on that.

MR. CLARK: Do you incorporate the summing lever design -- well, that goes back to the rudder package itself. Is that summing lever design used on other packages other than the 737?

THE WITNESS: I didn't follow your question.

MR. CLARK: You design the summing levers on the 737 rudder package?

THE WITNESS: Yes.

MR. CLARK: Are those summing levers used on other --

THE WITNESS: No.

MR. CLARK: Completely different?

THE WITNESS: Completely different.

MR. CLARK: Now, back to the concentric valve. For the 737 design in the rudder package, a similar design is used on the 727 for what part? The elevator?

THE WITNESS: The elevator. Yes.

MR. CLARK: Are you aware of any failure modes or failures or malfunctioning servo valves on the 737 rudder package?

THE WITNESS: Yes.

MR. CLARK: Would you describe those?

THE WITNESS: One unit in the extreme extreme worst condition, the pressure can reverse.

MR. CLARK: Okay. That's a -- is that from the MacMore unit? That design?

THE WITNESS: Yes.

MR. CLARK: And that's the only type of design -- that's the only unit you're aware of in the --

THE WITNESS: That's the only unit I'm aware of.

MR. CLARK: And that was one that became apparent in the investigation of the Colorado Springs accident or an outgrowth of that?

THE WITNESS: During the investigation. Yes.

MR. CLARK: For the other dual concentric valves that are used on those other airplanes, are you aware of any types of failures that have occurred on those valves?

THE WITNESS: I don't have the knowledge.

MR. CLARK: You would not be the person to ask for that?

THE WITNESS: Right.

MR. CLARK: Okay. I have no further questions.

CHAIRMAN HALL: Mr. Schleede?

MR. SCHLEEDE: Okay. Sir, are you aware if there's any testing done during initial design phase and certification for the PCU unit, including the servo valve, for chip shear? Jamming of the servo valve from chips?

THE WITNESS: I don't have the knowledge.

MR. SCHLEEDE: You're not aware of that?

THE WITNESS: I don't know. Maybe there is, but in those days I was not involved in the valve area, so I don't have any idea if they did or not.

MR. SCHLEEDE: Was there any other testing for mechanical failures in any of the other linkages, full scale testing for jams?

THE WITNESS: We test to the specs limit load.

MR. SCHLEEDE: Are you aware of any -- you may have answered this question -- of any malfunctions or jams or conditions of that type in the summing levers, in the linkages of the PCU that could cause a runaway rudder?

THE WITNESS: Not on the 737.

MR. SCHLEEDE: You're not aware of any occurrences?

THE WITNESS: Not aware. Even we tried to find some, but no.

MR. SCHLEEDE: Okay. Are you a designated engineering representative for the FAA

THE WITNESS: No.

MR. SCHLEEDE: Do service difficulties that are reported with these products that you work on, are they reported to you?

THE WITNESS: No. They report to the projects.

MR. SCHLEEDE: To which office?

THE WITNESS: To the project.

MR. SCHLEEDE: Project engineers?

THE WITNESS: Yes.

MR. SCHLEEDE: That's all I have. Thank you.

CHAIRMAN HALL: Mr. Sheng, you designed this. You're the original designer, correct, of the power --

THE WITNESS: Just the linkage.

CHAIRMAN HALL: Of the linkage. Okay.

And I may be getting -- I may need to address these questions to Mr. White tomorrow, but I had the pleasure of going to visit your office in Irvine and I noticed that they are constantly -- these units are being brought in to be serviced. Do you or are you made aware of any of the units if there was problem with galling or a problem with the secondary -- the second slab? Is that anything that would be brought to your attention or what's the process since you have expertise in this area.

THE WITNESS: The unit brought back is actually brought to different divisions, which is the service division. I'm in the -- division. So different divisions. Unless I request information, otherwise I will not get them.

CHAIRMAN HALL: All right. Well, do the parties have any additional questions? Does Parker Hannifin have any questions for this witness?

(No response.)

Mr. Sheng, we appreciate you coming on so late in the evening and you're excused. Thank you very much.

(Witness excused.)

CHAIRMAN HALL: This hearing will reconvene at 8:30 a.m. in the morning to begin with the testimony of Mr. Paul Cline.

(Whereupon, the proceedings were adjourned at 6:02 p.m., to be reconvened at 8:30 a.m. on Wednesday, January 25, 1995 in the same place.)