

1 and XI of the reports which contrast the NASA culture
2 with other high-reliability cultures. And there's
3 much to learn from this. And we expect in the course
4 of these hearings to try to distill what's the best
5 lessons that the DOE should learn from that.

6 Thank you particularly for taking the time
7 to do this because I know that you're running toward
8 the end of your commission on the Columbia Board, and
9 your time's valuable, and I'm glad you chose to spend
10 it with us. Thank you.

11 CHAIRMAN CONWAY: Jim, anything?

12 MR. McCONNELL: No, nothing.

13 CHAIRMAN CONWAY: Okay, General?

14 MAJ. GEN. BARRY: Okay. Well, good
15 morning Mr. Chairman, and ladies and gentlemen. It is
16 indeed an honor to be here today. My intent here is
17 to go through some introductory remarks, and then I'm
18 going to show some slides, and then we'll open it up
19 for questions and answers as you see fit.

20 I would like to also just state at the
21 very beginning here that what I think I'll be able to
22 present here is a summary of about nine months of work
23 by some very dedicated Americans in trying to come to
24 the root cause of what caused the Columbia accident.
25 You'll find that we have basically arrived at two

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 causes, a technical and an organizational cause. The
2 technical cause, particularly for this group, I think,
3 will be of interest.

4 But probably the most compelling element
5 will be the organizational, culture, and managerial
6 elements, because the lessons learned that we derived
7 from that I think can be applied not only to public
8 but also to private organizations. But this is unique
9 because this is a very complex organization that had
10 a failure. And I think we can all learn considerably
11 from that.

12 Let me begin by just saying that at the
13 end of the report you will notice, if you had a chance
14 to look at it, that we have a patch that memorializes
15 the three human space flight accidents. And we
16 include Apollo 1 in there in 1967, the Challenger
17 mishap in 1986, and of course Columbia. And on the
18 back it says, "To the stars despite adversity, always
19 explore." And that's kind of the context that the
20 board took when it first took its charter and moved
21 on.

22 Now, President Bush on February 4, just
23 three days after -- the mishap, of course, occurred on
24 February 1 -- he said, "The cause of exploration and
25 discovery is not an option we choose, it is desire in

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 the human heart. We find the best among us, send them
2 forth into unmapped darkness, and pray they will
3 return. They go in peace for all mankind, and all
4 mankind is in their debt." And it's with that kind of
5 focus on that legacy, particularly for the seven great
6 explorers who lost their lives on February 1, that we
7 began our investigation.

8 And we all know that 2003 started as a
9 great year, certainly for the celebration of 100 years
10 of flight with the Wright Brothers. But unfortunately
11 on February 1, the year began on a note of sudden and
12 profound loss. As the Columbia Accident Investigation
13 Board formed, from day one we felt that we were
14 laboring in a great legacy of the 107 crew: Rick
15 Husband, Willie McCool, Mike Anderson, Dave Brown,
16 K.C. Chawla, Laurel Clark, and Ilan Ramon.

17 The Board owes a lot of thanks to a lot of
18 people because it was a staff of about 120 that
19 reviewed 30,000 documents, over 200 interviews, more
20 than 3,000 inputs. And about 400 NASA engineers were
21 involved, and 25,000-plus debris searchers on the
22 ground from every state, local government, Federal
23 Emergency Management Agency [FEMA], Forest Service,
24 Boy Scouts. So a lot of great effort by a number of
25 great Americans.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 Our view stated from the outset is the
2 space shuttle is not inherently unsafe. Now it's
3 still a development vehicle with inherent risks, and
4 we would have said it was unsafe if we felt it to be
5 that way. We were under no pressure to keep it
6 operating, and the International Space Station [ISS]
7 was not a factor in our deliberations. However, it
8 can be operated a lot more safely, and that's what we
9 concluded, and it will not last forever.

10 As I mentioned to the Board earlier in our
11 conversations this morning, we are entering an era of
12 something we've never been before. We are entering an
13 era of a reusable space vehicle that is aging in an
14 R&D [Research and Development] environment. We've
15 never had that before. Of course, with Mercury and
16 Gemini and Apollo, they were one-time-use vehicles.
17 So with that realization, I think, there's a lot that
18 we can gain, not only from aviation but from the
19 nuclear industry, DOE, and certainly at NASA.

20 We looked into technical, organizational,
21 and cultural aspects to truly lessen the chance of
22 another accident. Most of you realize that when an
23 investigation usually starts and something goes wrong,
24 you'll find the widget that broke, find the person
25 closest to the widget, you'll either fire or replace

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 that person, and move on. We didn't want to make that
2 mistake by only leaving at that point. We wanted to
3 make sure that we got down into the organizational
4 elements and made sure that we didn't have a repeat of
5 Challenger, because we did see a lot of echoes with
6 Challenger in 1986.

7 The Board was independent. We were
8 reporting to numerous constituencies: the American
9 people, the White House, Congress, the Astronaut
10 Corps, their families, and the rest of the NASA
11 family. And we just didn't look into the Columbia
12 accident for the space shuttle program, but we looked
13 at it as a whole.

14 We examined physical failures, weaknesses
15 from history and evident in NASA's organization, and
16 other significant observations that might cause a
17 future accident. Now, let me state from the outset,
18 NASA is an outstanding organization. I could spend
19 days, if not weeks, talking about the profound
20 accomplishments, and outstanding history, and great
21 number of people that we have in NASA. The mission is
22 unique. It's stunning in its technological
23 accomplishments and a source of pride and inspiration
24 without equal in the United States. However, Columbia
25 did happen. It was a turning point in a lot of ways.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 We've called for renewed debate in manned space
2 flight, and a renewed commitment to human space
3 flight.

4 Space flight is far from routine. It
5 involves substantial elements of risk and needs to be
6 recognized for those risks. And we can never take it
7 for granted. And we owe this to the legacy of the
8 Columbia and her crew to get to the heart of the
9 matter.

10 Now, there are causes in any mishap, and
11 we found two main ones: technical cause, a physical
12 cause, and an organizational cause. Let me stand up
13 now, if I may, and we'll start the presentation on the
14 PowerPoint slides. I have some more to say about
15 that. Next slide, please.

16 This is what I'll cover, a little bit
17 about the causes, and summary, and the formulation,
18 but basically the two parts. This is the technical,
19 and this is the organizational element, and a look
20 ahead, and a little bit about recommendations. We'll
21 go through that. Next slide.

22 First of all technical cause. Frankly
23 stated, the foam did it. The foam came off, hit the
24 left wing, we had a perforation, a crack in there on
25 launch. And then, of course, on reentry, superheated

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 air entered the left wing and ended up in the
2 catastrophic loss of the orbiter. Effectively what
3 happened on the launch on January 16, 81 seconds after
4 launch, is when the foam hit the left wing. We'll
5 talk more about that. Next slide.

6 Organizational causes. Much more
7 compelling in the sense that it was harder to get our
8 hands around it. We wanted to make sure, again, we
9 just didn't focus on the technical elements. But
10 there were issues of culture, organization, and
11 management that we found to be causal in this mishap.
12 We treated the technical cause and this cause as
13 equals.

14 Reliance on past success, organizational
15 barriers, lack of integrated management, informal
16 chain of command, communication problems, all of those
17 are things that we arrived at, and we'll talk a little
18 bit more in detail as we go through the brief. Next
19 slide.

20 Of course this is the crew. Seven
21 dedicated explorers. Six of the seven are in the
22 military. The only one that wasn't in the military
23 was K.C. And of course Ilan was from Israel. Next
24 slide.

25 107; This was the 113th flight for the

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 space shuttle. This was the 28th mission for
2 Columbia. And remember, Columbia was the first space
3 shuttle. It was launched April, 1981. And this was
4 a 16-day mission that started on January 16.

5 Now just real quickly, we'll go ahead and
6 hit on "Shuttle 101." A lot of you are familiar with
7 this, I know, but the point to be made is I'd like to
8 just show this for the solid rocket booster and the
9 external tank. The external tank is as tall as the
10 Washington Monument. We sometimes lose that
11 perspective. And that whole external tank, as it
12 appears to be golden here, is entirely covered with
13 foam. The entire thing is covered with foam. And if
14 you remember the launches that we saw with Apollo,
15 Mercury, and Gemini, pieces of ice falling off. Well,
16 the capsule was on top. Unfortunately this time, with
17 this design, the shuttle was on the side. So this
18 foam is built there to prevent ice formulation, which
19 has a lot more density than foam does, to prevent that
20 from formulating and then coming off on launch. So I
21 want to bring that to your attention as we talk about
22 it.

23 All right. Let's talk about, next slide.
24 We're going to talk about the formulation of the Board
25 real quickly. A very distinguished group. I don't

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 know how they picked a fighter pilot to be part of
2 this, but I managed to get on there. Of course
3 Admiral Gehman, a retired four-star Navy admiral, was
4 our Chairman - did an outstanding job on leadership
5 and bringing the Board together.

6 We have Sally Ride that you know. We have
7 Dr. Osheroff, who is a Nobel Prize winner. We have
8 representatives from the Army, from the Navy and Air
9 Force represented there. Sheila Widnall, former
10 Secretary of the Air Force, as a case in point. Scott
11 Hubbard, who runs Ames [NASA Ames Research Center].
12 Then we've got Roger Tetrault that some of you may
13 know from DOE. He was the chairman of McDermott
14 [International].

15 So, a group that really brought a lot of
16 diversity and certainly a tremendous amount of
17 knowledge. Next slide.

18 All right. We call this the Gehman test.
19 But now I'm going to talk about the technical issue.
20 But what we wanted to make sure, if we were going to
21 arrive at a cause on the technical side, we wanted to
22 be able to stand with some authority and say, okay,
23 this is what we thought the cause would be. You
24 notice in our causal statement on the technical side,
25 we didn't say, "Probable cause;" "Most likely cause;"

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 we said, "The cause."

2 And the reason we were able to come to
3 that conclusion was it passed all of these tests and
4 arrived at the same point. And the point was that the
5 foam caused the issue. So we looked at aerodynamics,
6 thermodynamics, timeline, imagery, debris. All of it
7 led us to the same conclusion. I'm talking about the
8 technical cause now. Next slide.

9 So let's talk about that in more detail.
10 Next. All right. This launch occurred, and I'm going
11 to show you where the culprit is. The culprit is this
12 bipod foam. And I'm going to show where exactly that
13 is located here in just a minute.

14 This foam is about this high. [The speaker
15 held his hand at his waist height, approximately 45"
16 from the floor.] It weighs about 2.6 pounds. It is
17 covering a very complicated geometric connection point
18 from the external tank to the orbiter. And this is
19 the piece that fell off that caused the mishap. So go
20 ahead, and let me show you exactly where that is now.

21
22 This is the launch sequence. You'll
23 notice the information on the top. It's got Mach
24 number and speed and height. Well, here we're going
25 three, four, five thousand feet. Of course, the

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 external tank is feeding the orbiter with liquid fuel,
2 but the solid rocket boosters there are solid fuel.
3 At about 81 seconds you'll see this is the culprit
4 right here. Bipod foam. And this is what comes off
5 at 81 seconds. It occurs at about 2.4 Mach at about
6 65,000 feet, and it hits the left wing right about
7 here. This is the main landing gear door on the left
8 side.

9 The piece comes off, and it comes off in
10 actually three chunks, one larger and two smaller.
11 The two smaller do not hit the wing. The larger piece
12 does. We think that was about a 1.6 pound piece of
13 foam. It hits it at about 500-plus miles per hour.
14 And what that amounts to in foot pounds of pressure is
15 about 8,000. Hits it, and this is just a translucent
16 element just to demonstrate it. Okay, we can stop
17 there. All right, so this is 65,000 feet, Mach 2.4 -
18 2.5.

19 Okay. I want to show you some video,
20 real-life video. Here is the launch. From here it
21 goes over the water. About right here is when the
22 foam comes off at about 81 seconds. Okay, right
23 there. We only had two cameras. Unfortunately, NASA
24 was not maintaining the quality control on their
25 cameras as much as we would have liked. We didn't get

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 the quality that we wanted. We had the experts in the
2 nation come together to try to enhance it to the best
3 of their ability and this is the best that we could
4 come up with. Go ahead and show.

5 Now it comes off the left side, of course.
6 And this is just a recurrence over and over and over
7 again of the foam coming off. But you can see it's a
8 pretty dynamic hit. And immediately, they arrived at
9 the conclusion that it didn't go over the wing, it
10 went under the wing. So they unfortunately arrived at
11 a conclusion it didn't hit the leading edge, it hit
12 the bottom of the left wing, when in truth of fact it
13 did hit the leading edge and at a pretty good
14 velocity. So that's one view. Next slide.

15 Now let me give you the other view from
16 this camera down further south. This one was really
17 out of focus and didn't give us a whole lot of help.
18 But if you look very carefully you can see the foam
19 coming off and hitting the left wing. There it is,
20 and it comes in, hits the left wing. There's no
21 apparent damage, certainly with lack of quality on
22 this film, to be able to arrive at the conclusion that
23 this thing really did cause damage. But I will show
24 you how we arrived at a final determination that it
25 was, in fact, the cause.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 Okay, we'll take a look at, next slide.
2 All right, so there's the culprit. There's where it's
3 located. And this is what that foam covers, a very
4 complicated geometric connecting point. Okay, let's
5 go through the bipod. I want to show you in
6 appreciation of how that is formulated, what's
7 underneath it. There's the bipod connecting point.
8 Remember there's some connecting points on the bottom
9 port, but this is up at the top. And this is what's
10 underneath that foam. And then there's some ablated
11 material that actually we concluded didn't serve any
12 real function but had always been there, so they never
13 removed it. But this is the connecting point from the
14 external tank to the orbiter.

15 All right, I want to show you how this is
16 prepared. Go ahead and link on this. It's
17 interesting. Imagine the external tank sitting in
18 Michoud, which is near New Orleans, and all they do is
19 they spray it. They don't build it and then glue it
20 on it. They actually spray it on, this foam. And
21 they do it in a very controlled climactic environment,
22 temperature, and humidity. And it takes them about a
23 week to do all of this.

24 But what they do is they spray it over
25 there in a very, again, geometrically challenging

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 area. So you can imagine how hard it is to get foam
2 under all the little crevices. And then they spend
3 the next week carving it out. It's like an architect
4 trying to -- they've got specific angles, and specific
5 distances, but every one of them is unique. None of
6 them are exactly the same. And I'll show you how we
7 determined that to be a fact, too. This is the end
8 result on how they put it together. But this is the
9 piece of foam that killed the astronauts.

10 All right, well, here's the trajectory,
11 roughly the size, and came at it about 500 miles an
12 hour. And trajectory you can see. Not the whole
13 piece came off, we just think a part of the piece came
14 off. But it was 1.6 of the 2.6 pounds of foam. Next
15 slide.

16 All right. Well, if that was the doer,
17 what was the receiver on this hit? And that's the
18 left wing. This left wing is a very unique and
19 amazing piece of technical capability that dates back
20 to '70s technology. I will tell you a question I
21 asked the astronauts we had talked, after we learned
22 this, and I didn't know this before the mishap of
23 course. But I asked them how thick do you think the
24 leading edge is. And if you look at this picture
25 here, it kind of implies that it's pretty thick. In

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 truth of fact it's a quarter of an inch thick. A
2 quarter of an inch thick. And it's an amazing piece
3 of technology.

4 Now there are 22 of these panels, numbered
5 1 through 22 on each side of the wing. And they cost
6 \$850,000 a piece, and almost take about six months to
7 make per panel. So very sophisticated. Remember,
8 this is not ablative material that we saw during the
9 early launch of the capsules. I mean, this is
10 reusable as we go along here. But it's only a quarter
11 of an inch thick. Okay, next slide.

12 So, impact location we think was panel
13 number 8 which is right on the curvature with a shock-
14 shock interface on the wing, for those of you who are
15 aerodynamic experts, and about 500-plus in miles an
16 hour. Next slide.

17 And it kind of came across. We did the
18 best we could in enhancing the photography, but
19 there's no evidence there that there's any damage to
20 the left wing after the hit. So what do we do to try
21 to arrive at a conclusion? Next slide.

22 What we did was, it turns out that we did
23 have a sensor, and this is an interesting story. This
24 is the MADS [Modular Auxiliary Data System] recorder.
25 Bottom line, this is a recorder that you cannot get

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 your hands on until after the shuttle comes back. It
2 is not a black box. A black box in an airliner is
3 meant to be built to withstand high pressures and
4 explosions and all this other stuff. This was just
5 encased in a regular old metal case. It was like the
6 old reel-to-reel recorders that some of us remember
7 from music in the '70s. And it is unbelievable that
8 we recovered this.

9 Now this orbiter has 4,000 sensors that
10 have telemetry down to the ground. There are a lot of
11 sensors that go into this MADS recorder that are not
12 telemetry down to the ground. So if we did not
13 recover this recorder, we would have been hurting.

14 Now here's the story. The engineers were
15 able to predict based on other debris we picked up
16 around it from the ground where this thing was on the
17 ground. They were so confident, they sent a team out
18 and said, "Look here." The team went out, couldn't
19 find it. Again they were so confident it had to be in
20 that area they sent them out again, and darned if they
21 didn't find it under a bunch of brush. It was in
22 pristine condition. It was a marvel that it landed
23 up-side, it didn't land in the water, and it didn't
24 have any serious damage. Because of that, we were
25 able to get some data. This is the key one.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 This is where the location of that sensor
2 was behind panel number 8. Remember I said panel
3 number 8 was where the hit [occurred]. But panel
4 number 9, I'm sorry, panel number 9 is where the
5 sensor was. And this is where it's located behind
6 about where the spar is. Well, what it did tell us?
7 Next slide.

8 What it told us was the temperature
9 increase of about seven degrees on launch. Now this
10 is, each one of these colors represents a different
11 launch. I draw your attention to the black one. This
12 is Columbia on the mishap. Most of these others on
13 launch will go down and go up one bit. One bit is
14 about two degrees. Columbia went up three bits, which
15 arrived at about seven degrees. That allowed us to
16 arrive at a conclusion that it was damaged, and there
17 was some kind of a problem with the left leading edge
18 on ascent. Because we needed some kind of evidence to
19 prove that it wasn't a micro-meteorite or something
20 like that. And we did conclude that on launch there
21 was a problem. Next slide.

22 Now, jump forward. We have now launched
23 into space. It is now the second day. What we did
24 was after the mishap, and that's a key point, after
25 the mishap, we went to the Air Force, and we said

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 please look at all of your radar, any photography that
2 you've got to give us any clue.

3 What they did was they looked at over
4 3,000 optical and radar observations. And what they
5 discovered was on the second day, there was something
6 that was paralleling the orbiter and that eventually
7 re-entered the atmosphere and burned up in about two
8 days. And we wanted to try to figure out what that
9 was, especially as we developed our hypothesis on the
10 technical cause. So go ahead and hit there, Matt.

11 Now this is an example on one of the
12 radars. This happens to be up in Massachusetts. But
13 we have an Eglin, Beale, Navy. This is at Cape Cod
14 and Kirkland. That helped us get some information.
15 The information we got was -- next slide.

16 It took us two days to track this piece,
17 but something was paralleling the orbiter, and it
18 eventually re-entered. Now some of you know this,
19 some of you don't. But most of the time the orbiter
20 is flying upside down in regards to the Earth, and
21 it's flying backwards. Because if it takes a
22 meteorite hit, if it hits the engines it's no big deal
23 because they've already used the engines. They're not
24 going to use those anymore. Now they do use retro-
25 rockets to maneuver the shuttle in space, but they

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 don't need the engine back there.

2 So anyway it's flying backwards. And then
3 about the second day, our radar in the Air Force
4 determined that something was flying parallel. We
5 don't know exactly where it came because of the radar
6 cross section distinctions, but we know something came
7 off of it. And what we ended up doing was, we
8 surmised it came from this area. But we took every
9 single possible item that we could think of that could
10 have come off, from blankets to pieces to parts to
11 parts of the wing, and we sent it to Wright-Patterson
12 Air Force Base and did two things. We looked at the
13 ballistics, and we looked at the radar cross section.
14 There was only one piece that solved the problem, that
15 matched the radar cross section and the ballistic
16 reentry and the burn cycle on a piece. And that
17 happened to be a part of the reinforced carbon-carbon,
18 in other words, the leading edge.

19 So it helped reinforce for us that
20 something was wrong with that leading edge, and
21 something came off of it on the second day. Couldn't
22 completely conclude that that was absolute, but it
23 helped us in our analysis. Okay, let's go back.

24 So now, next slide, I want to jump to the
25 reentry sequence. So now we've gone through the

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 launch. We've gone through 16 days in flight. And
2 now they're coming back. Now remember, nobody knows
3 there's a problem. I'll go into a little bit about
4 the analysis, but they saw the foam hit after the
5 second day reviewing the film. They've done their
6 analysis at NASA. They've concluded that it is not a
7 safety-of-flight issue. Okay, and we'll talk a little
8 more about that when we get to the organizational
9 causes.

10 I do want to show you the reentry hit.
11 This is 8:44. We lose the orbiter on the hour. So at
12 about 16 more minutes, we're going to lose the
13 orbiter. So here's the reentry sequence. Some of you
14 know this. Here is Florida. On the other side of the
15 planet is when they start this reentry. And what they
16 do is what I call in fighter pilot terms a split-S,
17 but much more complicated than that. But here they
18 are over Australia. Again, you'll see Mach number,
19 and speed and altitude. So here we are at 820,000
20 feet.

21 You'll notice that the left wing is
22 opaque. We did that for demonstration purposes. All
23 of those little green points on the left wing are
24 sensors that are either telemetry to the ground or to
25 that MADS recorder. You'll notice that everything is

1 normal. They come in about a 40-degree angle of
2 attack in penetrating the atmosphere. They're
3 starting to heat up.

4 The entry interface doesn't really start
5 until they get to 400,000 feet, so about right now is
6 when the entry interface starts at 44 minutes past the
7 hour. We've got a high speed here. Green is good,
8 and blue is bad. So we'll start there; it's a little
9 different. Something is wrong with the left wing.
10 Again, they don't know it on the ground, they don't
11 know it in the cockpit, but we know from telemetry
12 now, as well as from our sensor, that something is
13 eating at that left wing.

14 It finally burns through at 48 minutes
15 past the hour, burns through the leading edge, and
16 super-heated air is getting in there. Not plasma as
17 some of us have used the term before, but it's super-
18 heated air. It is now 49 minutes past the hour,
19 249,000 feet. The orbiter makes a right-hand kind of
20 bank slice turn, helping getting us through the
21 atmosphere. This is normal. It's all being flown by
22 the autopilot. The crew is in the cockpit putting on
23 their gloves, you know, drinking water, getting ready
24 for landing at Kennedy.

25 So now we're at 240,000 feet. You can see

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 Mach 24. Now look at, those of you who know knots and
2 airspeed, 74 knots. So if you didn't have the heat,
3 and you stuck your hand out the window so to speak,
4 which you can't do obviously, it would be about
5 driving your car at 74 miles an hour, 74 knots.
6 Obviously the heat is the issue. But there's not a
7 whole lot of molecules of oxygen.

8 This is at night still, in the early parts
9 of the morning, so it's still dark. Here's the coast
10 of California that's coming up. They're in a right-
11 slicing turn. You'll notice at about 56 minutes past
12 the hour they go into a left bank turn which is, you
13 know there's a little bit of yaw so they're not going
14 to quite get to Florida if they don't come back a
15 little bit. Nothing's unusual. But however right now
16 we're starting to see super-heated air burn through
17 the spar. So now it's getting into the wing in its
18 entirety.

19 Again, no indications on telemetry to the
20 ground or in the cockpit that there's a problem here.
21 You'll see some sensors that are reading off-nominal
22 here because some of the air flow, and there is some
23 there, oxygen, not much, but the temperatures are
24 reading different than they had normally been. So we
25 started seeing that.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 Now debris is coming off. As soon as it
2 crossed the coast of California, amateur photographers
3 were taking videos of it. And we were able to get all
4 that. But debris is coming off, and probably a lot
5 earlier than California. We don't know that because
6 we didn't have anybody taking film. But we asked the
7 American citizens to donate their film, and they were
8 great, and we were able to -- I'll show you some of
9 that here in just a little bit.

10 Here we are at 220,000 feet. Debris is
11 coming off. Cockpit doesn't know it. NASA doesn't
12 know it on the ground. Super-heated air is now
13 getting ready to enter the left main gear. We're
14 crossing the coast of New Mexico, and approaching
15 Texas. Here's the sun. The sun's coming up, so it's
16 getting lighter. And there is some serious
17 disruption. At 56 minutes it goes into its normal
18 program, everything looks nominal, left-hand bank
19 turn. Again, at 40 degrees angle of attack, not much
20 yaw. Okay, speed is about 13,000 miles an hour. And
21 then Mach is still about Mach 20.

22 Again, we lose the orbiter on the hour.
23 So now 57 [minutes past the hour]. Communications are
24 now going on that, hey, we're getting a reading of
25 some bad temperatures in the sensors in the left main

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 landing gear. Not too unusual. Sensors have gone bad
2 before. Communications go from the cockpit. It's
3 acknowledged by Colonel Husband [Commander of Columbia
4 Shuttle Flight STS-107], and that's the last
5 transmission that he makes. Remember, we lose the
6 orbiter on the hour.

7 You're going to notice that the retro-
8 rockets here fire. And this shuttle is working real
9 hard to maintain this attitude. And, fortunately, all
10 four retro-rockets fire, never seen before, never
11 really normal, trying to stay there, just before we
12 lose signal, and she disrupts. So here we are
13 approaching loss of signal. Four retro-rockets fire,
14 and that's what happened, and then we lost the orbiter
15 after that.

16 All right, let me go back to some slides
17 here. This is at 44 minutes past the hour.
18 Everything, remember green in this case is good, blue
19 is bad, and everything is normal. I will draw your
20 attention to the wiring. We started seeing some off-
21 nominal readings of sensors back here, but that's not
22 where the heat was. The heat was here. And what
23 happened was it burned through the wiring here.

24 So let me start at 44 minutes past the
25 hour, everything looks good. Next slide. Well, at 48

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 minutes past the hour, we have confirmation from
2 sensors that the super-heated air does burn through
3 the leading edge -- remember, I said it was only a
4 quarter of an inch thick. By the way, this quarter of
5 an inch thick is protecting 3,000 degrees of
6 temperature. But there's a boundary layer even at
7 that altitude that's about six inches in front of it
8 that has 8,000 to 10,000 degrees. So this quarter of
9 an inch of reinforced carbon-carbon [RCC] is
10 absolutely a marvel. Well, it failed here because of
11 the impact of the foam on ascent. And at 48 minutes
12 temperature is getting in there. Next slide.

13 We know that from the sensors. This is
14 the back part of the spar. Okay, so this is about
15 right there, where that sensor is on the back side.
16 At 51 minutes past the hour, we [about] know burn-
17 through through the spar now; it's going to get into
18 the left wing because of sensor readings. Next slide.

19 And super-heated air starts going up and
20 down the left wing. And the wire bundles -- remember
21 when I pointed out to you -- this is what it looked
22 like. This is an actual picture of Columbia. And the
23 burn-through starts on this wiring. Next slide.

24 Here we are at 52 minutes past the hour,
25 and these sensors are starting to go offline because

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 this wire has gotten burned. And the first indication
2 to Mission Control was about 52 minutes, when they see
3 four elevon-actuated temperature sensors that are
4 starting to go off-nominal. Next slide.

5 Well, the super-heated air finally makes
6 its way into the left main landing gear at 56 minutes
7 past the hour. Next slide. And this is when we lose
8 signal. Blue is bad, so all these sensors have gone
9 offline. All right, this is where we're located,
10 about over Texas. It was in a left-hand bank turn,
11 and at about 18 seconds past the hour is when we had
12 catastrophic break-up. Next slide.

13 All right. I mean to spend a little time
14 on debris reconstruction. An amazing amount of
15 Americans did some incredible work in trying to pull
16 the pieces back. We actually recovered about 38
17 percent of the weight in the orbiter, which is pretty
18 phenomenal. We'll probably have hunters and hikers,
19 you know, for the next 10 or 15 years bringing pieces
20 of the shuttle. But we were able to get that much
21 back. Next slide.

22 Here is the debris pattern. You can see
23 from Dallas, it's located here in Nacogdoches. What we
24 know is there's parts and pieces up here, but this is
25 much more mountainous region, and we weren't able to

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 get [to it]. But this is all pretty populous. It's
2 an absolute godsend that on Saturday morning when this
3 occurred that nobody was hurt, nobody was injured, and
4 nothing was really damaged by all those pieces and
5 parts coming out of the shuttle. Next slide.

6 Oh, I'm sorry, let's go to the amateur
7 video. I'm going to show you a couple of
8 demonstrations. Again, this isn't professionally
9 done. These are all amateur videos, but there's two
10 sequences I want to show you. One is debris number 6.
11 This is Venus, actually. And the shuttle you can see,
12 you're going to have a flash here in a minute of
13 debris coming off, right there. And even the guy who
14 was taking the photograph didn't see it until after we
15 collected it. But it gave us a good time location
16 continuum to position this correctly.

17 So there was a number of them. There were
18 like 16 of them that we clearly saw debris, and then
19 toward the end, I'll show you this last one where you
20 see the break-up. There happened to be an Army
21 helicopter flown by a Dutch and a Belgian in training
22 at Fort Hood. And they were able to pick this thing
23 up on their infrared scope. And this is the final
24 seconds of the Columbia. And you can see it breaking
25 up. Leading parts were the three engines, and then

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 other parts of the orbiter as it broke up. Pretty
2 sobering.

3 All right, with that understanding, I want
4 to move to the next point. Here is left is red, and
5 right wing is blue. And as supported our hypothesis,
6 the left wing obviously disintegrated before the
7 right. So we can see that from the debris pattern.
8 Next slide.

9 And we reassembled this at the floor of
10 the hangar in Kennedy Space Center. Here's the nose.
11 The left wing is actually -- think of the orbiter as
12 upside down. The left wing is over here. So we're
13 looking at the bottom part of the orbiter from the
14 view you have now. Next slide.

15 But here's the left side, and here's the
16 right side. We didn't get as much from the left side
17 as we did from the right side, and that kind of makes
18 sense. And what we were able to do -- next slide --
19 it's absolutely amazing what the technicians and
20 engineers were able to do. They could identify every
21 part almost without exception and try to put it back
22 on the orbiter. And we did it with a three-
23 dimensional re-enhancement.

24 And you can see the left wing here again
25 in support of the hypothesis that there was a burn-

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 through here in RCC. And we didn't quite recover
2 these pieces, but that made sense to us too. But it
3 really helped our analysis. Next slide.

4 All right. I want to talk about the doer
5 and the receiver, in my words. The doer of course was
6 the foam, and the receiver was the left wing. Let's
7 talk about the foam again. Unfortunately there were
8 six previous occurrences of this particular piece of
9 foam that came off. And you look at the dates -- '83
10 -- '90, '92, '92, '94, and look at this one. October,
11 a year ago. Just before the January launch, a big
12 piece came off.

13 Now, NASA wasn't aware of all of these.
14 They had seen four. We found two more in our
15 analysis. And this is only the ones we could see,
16 that weren't flown at night, and that weren't flown in
17 the weather. So on average, about 10 percent of the
18 time this piece came off. So there's probably three
19 or four more out there that we didn't see.

20 On all of these, none of these caused any
21 problems insofar as damage to the orbiter. This piece
22 came off and didn't hit the orbiter, it hit the left
23 solid rocket motor skirt. And it came off at 31
24 seconds and not 81 seconds. So it didn't quite have
25 the force that the one that hit Columbia. But there

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 were messages. There were signals. Next slide.

2 What other people don't really know is
3 that the orbiter has been taking hits from day one.
4 Unfortunately, the space shuttle was designed not to
5 take hits. In fact, if you look at the specifications
6 in the book, it says that it can take a 0.006
7 foot/pound of hit. That is a number 2 pencil dropped
8 from about here. [The speaker held his hand at
9 shoulder height, approximately 60" from the floor.]
10 Remember I told you that this piece of foam hit it at
11 500 miles an hour, 8,000 foot-pounds. That's not
12 0.006.

13 Unfortunately, it's been taking hits,
14 mostly on the belly of the orbiter at the tile level,
15 and not the leading edge. But they had some really
16 bad ones here. This is when a piece came off the
17 solid rocket motor at the nose cone. And as late as
18 1996, STS-87 [Columbia Shuttle flight commencing
19 November 19, 1997] had some. And most of the foam
20 coming off was the external tank. But there is some
21 debris on launch that spits up, that gets counted.
22 But every time they came back, we'll talk about
23 normalization of deviance, but hits were taken and it
24 got accepted as normal business, cost of business of
25 doing this. Next slide.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 Well, pretty dynamic area. This is
2 exactly when the foam came off on Columbia. It was
3 Mach 2.46 at about an angle of attack of two degrees.
4 We did with the computational flow dynamics a
5 reconstruction. You can see this is a very
6 challenging area. Lot of pressure this way, against
7 that. But by itself, we concluded that the foam was
8 structured not to come off. So something else had to
9 contribute to it. Next slide.

10 Well, what we found out is that we had a
11 whole bunch of external tanks down in Michoud in New
12 Orleans that were already built. The bipod foam had
13 been prepared and already made. So they're sitting
14 there. And we said okay, we'd like to dig into those.
15 So we cut into and dissected it. And we found all
16 sorts of interesting things. We checked the right
17 side and the left side, and we found problems. Next
18 slide.

19 We found voids and rollover and de-bonds,
20 de-laminations, and all sorts of challenging things.
21 As you remember, he's spraying the thing, and it's
22 kind of hard to get foam under every little piece and
23 crevice, and pretty geometrically challenging area.
24 Please.

25 DR. MANSFIELD: Does that foam survive the

1 reentry into the water?

2 MAJ. GEN. BARRY: Well, remember the solid
3 rocket booster separates at two minutes, and the
4 external tank separates at eight and one-half minutes.
5 So the answer is no. The external tank burns up on
6 reentry.

7 So the only proof that we have is they do
8 have separation cameras that take pictures.
9 Unfortunately on this one the angle was not, you know
10 you can never predict exactly how it's going to roll
11 off, and it was not able to give us a clear picture to
12 let us see what was there. But this is how we
13 dissected and found out that we have manufacturing
14 challenges and original design defects. Next.

15 Okay, let me go to the RCC again. This is
16 the reinforced carbon-carbon leading edge, quarter of
17 an inch thick. It doesn't look like quarter of an
18 inch, but think of it as a wraparound. But this thing
19 is just a quarter of an inch all the way around.
20 Pretty blank area there. Some insulation. Here's the
21 spar. It will eventually burn through the leading
22 edge and burn through the spar. Next slide.

23 This thing is a quarter of an inch thick.
24 It's made up of silicone carbide, which is like glass,
25 carbon-carbon reinforced, as some of you are familiar

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 with, and then silicone carbide. It's an amazing
2 piece of technological achievement. It radiates the
3 heat, it doesn't absorb it. And it certainly doesn't
4 ablate it. Okay, let's go back.

5 Okay. I just want to mention, then I'm
6 going to show you some impact testing. The aero-
7 thermal analysis we went through at Langley, and put
8 this thing in a different modes and try to figure out
9 what the aerodynamics was. We looked at burn-throughs
10 and wirings and forensic testing. All of this led to
11 this technical conclusion. Next slide.

12 So using the Gehman test again,
13 aerodynamic, thermal, timeline, imagery, debris
14 evidence, all of us concluded that the cause was the
15 foam coming off and hitting the left wing. Next
16 slide.

17 And we have proof and evidence, and this
18 is examples of breach in panel 8, and wind tunnel
19 tests, and temperature increases, and the panel's
20 launch imagery and left wing. So all of those, that's
21 just examples that allowed us to arrive at what we
22 thought was conclusive evidence that this was the
23 technical cause. Next slide.

24 DR. MANSFIELD: The knife-edge erosion on
25 panel 8, the significance I think it means that the

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 knife edge was exposed because of the break during --

2 MAJ. GEN. BARRY: Right. The debris talks
3 to, and it's really unbelievable what the technicians
4 can go. But we could see the heat pattern that was
5 generated by different debris that we were able to
6 recover. We could see the splash of the materials
7 that were recovered, that, you know, aluminum burns at
8 a certain rate. And then we have different parts and
9 pieces that burn. So all those things allowed us.
10 But that knife-edging element showed us the burn
11 patterns that, again, reinforced the conclusion that
12 it was panel number 8 where it went from there. Next
13 slide.

14 Well, to nail this thing shut, the final
15 thing we wanted to do was shoot foam at the RCC
16 leading edge. Now what we did was we reconstructed
17 the left wing and shot foam at it. And this is at the
18 right velocity. It had the density that we think, 1.6
19 pounds worth of foam. And hit at the right angle, the
20 correct angle, and put a significant hole in the left
21 leading edge. We're still getting push-back from NASA
22 that foam is not going to damage a leading edge.
23 Well, obviously it did here.

24 On the day of Columbia, on the launch of
25 January 16, it could not have made that kind of a

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 hole, because on reentry it never would have made it
2 to Texas. It would have broken up. But it did cause
3 some damage.

4 Let me show you the inside of it.
5 Remember I said on day two there was a debris that
6 came loose? We don't know exactly, but what you can
7 see here is the look from inside on this test. Pretty
8 compelling. And big pieces that could easily have
9 separated on day two, maybe not that large, but
10 certainly some piece could have. But pretty violent,
11 and pretty damaging. Okay, let's go back Matt.

12 All right, now I've spent quite a bit on
13 the technical issues, and go ahead, next slide. We're
14 going to now move, well let me just mention areas that
15 weren't a factor. You know, it's important to study
16 what you conclude not to have been contributory. So
17 we looked at everything, wiring to fuel spills to the
18 depo work, and sabotage, and micro-meteorites, and
19 foreign objects. None of them had any evidence that
20 would allow us to conclude that they were causal in
21 this mishap for the technical side. Next slide.

22 And then we go to the accident occurrence.
23 There was a story that we got from the one of the
24 books that we reviewed. We had a number of seminars
25 with safety experts. The story goes something like

1 this. There were two Canadian brothers who were
2 responsible for chlorinating a well in Canada. And
3 unfortunately they had a lot of cattle, and feces were
4 getting into the water, and they did not do it
5 correctly. People got sick, and a few people died.
6 Big investigation. Long end result was they found the
7 brothers didn't do their job right.

8 Well, when they started digging into the
9 investigation, remember I said the widget breaks, they
10 find the guy closest to the widget, and you either
11 fire or replace them, and then you end your
12 investigation. They did not choose to end it there.
13 They went further, and they found out there were a lot
14 of compelling organizational, cultural, and managerial
15 problems that dated all the way back to the Parliament
16 in Canada. Under-funding, lack of training,
17 bureaucracy, down-sizing, out-sourcing, all of these
18 things that we kind of saw in this.

19 It gave us proof positive that we just
20 didn't want to stop at the technical cause. So we
21 move into the organizational elements for history,
22 decision-making, and on. Organizational system
23 effects. Next slide.

24 Well, there's a lot of history on the
25 Challenger mishap that was echoes. There were a lot

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 of compromises made on the original design of the
2 shuttle, not unlike the original compromises that were
3 made in the nuclear industry. Budget cuts. You can
4 see the significant leveling off. NASA was working on
5 about \$3.5 billion. Seven billion of their 15 is
6 devoted to manned space flight, the space station, and
7 the shuttle. About 3.5 of the seven is shuttle. But
8 workforce reduced by 40 percent. And a mature and
9 reliable system.

10 I'm going to hit on this a little bit in
11 the sense that NASA declared in the early '80s that
12 the shuttle was operational. When you declare
13 anything operational, your mindset changes. Let me
14 give you an example. The Air Force has not declared
15 the F/A-22 operational yet, and it has over 17,000
16 sorties under its belt. This is 113.

17 But the decision was made to call it
18 operational, and in the early '90s, with the out-
19 sourcing efforts, a lot of decisions were made to out-
20 source more to the contractor. That's going to pay
21 some problematic, unintended consequences. And the
22 unintended consequences that the expertise, technical
23 expertise for the civilian government engineers went
24 down.

25 I'll give you an example. In 1990, there

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 were 48,000 government mandatory inspection points.
2 In 2003, there were 8,500. So it has gone down that
3 much on the out-sourcing and the privatization
4 elements. Next slide.

5 Also as part of this, from Challenger to
6 Columbia, replacement of the orbiter was supposed to
7 be -- this orbiter was designed to fly 10 years and
8 100 flights. It did not fly for 10 years, it flew for
9 22 years. And it didn't get 100 flights, on Columbia
10 it got 28 flights. So it was an aging spacecraft that
11 had gone longer. But they kept pushing out the
12 replacement. The board was a little disappointed that
13 there really was nothing on the books at the time of
14 the mishap for a replacement orbiter.

15 Fluctuating attitude towards investing,
16 space flight culture, how do we do things here.
17 There's a little arrogance that was evident. Perfect
18 place. Challenger occurred in 1986, but we have now
19 87 flights under our belts since then. We've been
20 there, we done that, we got the t-shirt. Next slide.

21 Decision-making at NASA was also
22 problematic. Remember, here's the bipod foam. It had
23 come off. They weren't listening as well to the
24 signals. It's great to have perfect hindsight when
25 you do these things and say, well, how could that

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 happen?

2 But as I mentioned to the Board earlier,
3 just in a little defense of NASA, there are over 1,600
4 single points of failure on this system. What that
5 means is they have a critical item list, and critical
6 item list number 1, if any one of those 16 items fail,
7 that will be loss of orbiter or crew or both. This
8 was listed as one of the critical item lists, but they
9 had already waived it, and they had looked at it, and
10 they had gone to what we call normalization of
11 deviance. If something goes wrong, and you notice it,
12 and you say okay, fine. Something goes wrong again,
13 you notice it, but still no damage, no occurrence, and
14 it just becomes a normal way of business, you accept
15 it as normal business. And Diane Vaughan, who had
16 written a book on Challenger, first coined the term
17 "normalization of deviance".

18 Not a whole lot of good trend analysis or
19 hazard analysis reviews. And there was some
20 scheduling pressure. It wasn't as problematic as
21 Challenger was, but it was incestuous a little bit.
22 And what they were focusing on was node 2 of the space
23 station. Node 2, my terms, like a tinker toy. You're
24 going to have that one piece before you start
25 branching it out. And this was February '04. They

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 were all driving to that. And that's one of the
2 things that was there. And it was evident in our
3 interviews that we had with a lot of the workers,
4 particularly at Kennedy. Next slide.

5 Decision-making again. We have problems
6 with the team. Interesting insight. Maybe because of
7 Challenger, if you have 10 units of energy on launch,
8 orbit, and reentry, 8 was used on launch, to get off
9 the planet. Very difficult thing to do. Another one
10 maybe for orbit, and then -- that was the kind of
11 division of energy levels.

12 The other thing that went along with that
13 is prior to launch, we saw evidence that the general
14 focus was: "Prove to me there is no problem," which is
15 a healthy attitude in an R&D environment. After
16 launch, it was: "Prove to me there is a problem."
17 Little different focus. And the mission management
18 team kind of went to that.

19 So we found that particularly in the
20 requests for photo. The engineers wanted second
21 confirmation, but the basic sense was, "Let's do the
22 analysis and see if there is a problem, and then we'll
23 go ask for photos." Well, they did the analysis,
24 concluded there wasn't a problem, and they never did
25 ask for the photos in an official capacity. A lot of

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 consternation. You've probably read some of the
2 reports on that.

3 Here's what's of interest. On the
4 analysis that was done, they used a tool called
5 Crater. Crater was designed in the Apollo era. It is
6 a semi-empirical formula that you take the entry
7 parameters of airspeed, and angle, and velocity, and
8 you take the density and apply it against the
9 material, and you conclude whether there's a safety-
10 of-flight issue.

11 This analysis was done by a young engineer
12 that had been trained over video teleconferencing
13 (VTC), had two practical looks, and he was the one and
14 only one that had really done this Crater. They just
15 moved the expertise from Huntington Beach to Johnson
16 Space Center. So there was movement going on. And
17 this was the first time that Johnson was responsible
18 for this kind of analysis. Before it had been done at
19 Huntington Beach.

20 They applied the analysis. They concluded
21 there was no safety-of-flight. However, they did not
22 conclude that it hit the leading edge. They concluded
23 it hit the belly. So the angle of impact was a lot
24 less than obviously hitting a curved piece of leading
25 edge. So they think it just kind of glanced off like

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 you would skip a rock off the water.

2 And interestingly enough, the conclusion
3 was that Crater had concluded that there was enough
4 damage to burn through and get to a point where it
5 would have been a problem. But Crater had always been
6 conservative. So Crater anticipated that it would
7 penetrate eight inches, my terms. They found it to be
8 two inches. So they subjectively looked at the
9 analysis and concluded there was no safety-of-flight,
10 even though Crater if applied told them they had a
11 problem. But the problem was on the belly with the
12 tiles, and not the leading edge. A lot of missed
13 opportunities they didn't quite get a hold of. Next
14 slide.

15 I do want to draw your attention to the
16 issue. We didn't ask the question until two months
17 into the investigation, but the question was: "Could
18 you have done a rescue effort?" And could they have
19 found, if they knew there was a problem. Maybe there
20 was no one who knew there was a problem.

21 So we said okay, here's the entry
22 parameters. Somehow on the third day of launch you
23 are told you've got a problem with the left wing.
24 Could you have gone out and looked at it? Yes, they
25 could have. And they could have designed an EVA,

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 extra-vehicular activity, outside. And they could
2 have hooked themselves up to the payload door. And if
3 you hook yourself on the payload door and stand in the
4 wing, guess what panel you're standing on? Panel
5 number 8. So they could have probably seen that they
6 had a problem.

7 Next question was, okay, if you found out
8 you had a problem, what could you have done about it?
9 Next slide. Turns out Atlantis was on the vertical
10 assembly building, ready to launch in about three and
11 one-half weeks. Could they have rolled that out early
12 and done a rescue, and done it?

13 Well, if they went through the process,
14 they would have to have waived or looked through
15 quickly on a lot of checks. If they had launched, the
16 shuttle Columbia could have lasted for 30 days. The
17 limiting factor is not oxygen, it's not water, it's
18 not food, it's their ability to recycle carbon
19 dioxide. But if they reduced their activities, slept
20 more, did less movement, they probably could have
21 lasted for 30 days.

22 Could they have gotten Atlantis out on the
23 pad, launched it? Remember, if they launched it, they
24 would have made a general risk that whatever caused
25 Columbia's problem they really weren't sure what would

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 happen to Atlantis. But they could have done a rescue
2 if they did tethering, and launched with four
3 astronauts, came back with seven for a total of 11.
4 It would have been very crowded in the cockpit, so to
5 speak, in the upper and the lower bays, but it might
6 have been possible. Next slide.

7 And this shows the other question we asked
8 them. Could you have repaired it if you knew there
9 was a problem? Very difficult to arrive at a
10 conclusion here, but if they could have stuffed things
11 into the crack, or it might have given them a chance
12 to survive. But highly unlikely, and very
13 problematic. Okay, let's go back. Next slide.

14 All right. Then we looked at the
15 organization. Now, there are two things, even though
16 you are looking at the words, I'd like you to just
17 concentrate a little bit on what I'm going to say here
18 for a minute. Bottom line here is: this was a complex
19 organization. Complex organizations fail in complex
20 ways.

21 What we found here was there was a
22 disconnect between balance of power and checks and
23 balances. What do I mean by that? The program
24 manager -- I want to date you back to 1986 and
25 Challenger. A lot of stovepipes, a lot of culture, at

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 Marshall, and Kennedy, and Johnson, and Thiokol. They
2 put a program manager in charge of all of it. Not a
3 bad thing to do. He was responsible for all of the
4 major elements for the program for the shuttle.

5 Here's where it was not good. The program
6 manager was responsible for cost, schedule, launch,
7 safety, waivers, technical assessment, and engineering
8 to a large extent. When conflicts came up in time and
9 schedule, you could make adjustments on waivers, and
10 safety, and things were done on that order,
11 unfortunately, over the course here. Nothing
12 duplicitous that we saw. It was just a normal
13 consequence of budget cuts, and you know now one
14 person is doing three things instead of just one
15 thing. And the normal consequences on that.

16 So the balance of power was not conducive
17 to an R&D environment. Remember they had already made
18 their determination they were operational. So when
19 you're more operational, you can take chances like
20 that a little bit more readily.

21 The checks and balances were not good
22 because in the case of safety, I want you to imagine,
23 my words again, the program manager is like a two-star
24 general sitting at the table, and the safety person is
25 sitting on the side and it's a young airman, or two-

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 striper. Kind of hard for him to raise his hand, or
2 her to raise her hand, and say I don't agree with
3 that. The checks and balances weren't there.

4 The other thing that was problematic was
5 the integration. They had an integration office.
6 They called it integration, but it was not an
7 integration office. It was more a technical
8 expertise, particularly on launch for wind shears, and
9 the software that was put in for launch. Very
10 technical-oriented, but not really an integration
11 office for the program.

12 So you've got stovepipes that weren't
13 talking to each other, and a perfect case in point on
14 that is when the foam came off one time that they saw
15 in the bipod region. Remember I said it came off six
16 times. They only knew about four. But one time it
17 came off they assigned the resolution and
18 investigation to the external tank. Stovepipe. Then
19 another time it came off, and they assigned it to the
20 orbiter. Stovepipe. Another time it came off, they
21 didn't assign it to anybody. All right. They
22 determined it not to be a safety-of-flight.

23 So those balance of power checks and
24 balances weren't there. There wasn't someone to do
25 the technical analysis that needed to be done if a

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 waiver was required, or a technical specification
2 needed to be put aside. There wasn't anybody
3 independent to review that. You put it with the same
4 organization that was responsible for cost and
5 schedule and so forth.

6 Now one of the things we found, I'll go
7 ahead and blow this up here, to show you the
8 disconnect on balance of power and checks and
9 balances. This blue is one person. And he had
10 responsibilities to the program, to the headquarters,
11 and to an intermediary. So how can you check
12 yourself, you know. And a lot of that was typical
13 down-sizing people, and one person's now required to
14 do four things, but before they were only required to
15 do one.

16 All right. They didn't demonstrate
17 characteristics of a learning organization. And we
18 studied two major theories, and that one was the
19 normalization theory and high reliability
20 organizations. And we found NASA not to be a learning
21 organization in a lot of ways. What we found out in
22 the case of Challenger is that the Navy had sent over
23 5,000 officers through training using the case study
24 of Challenger to try and understand a complex
25 organization that failed. NASA didn't do that to any

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 of their major senior managers. It wasn't part of
2 their culture to do this learning element. And
3 unfortunately they didn't go to school on it, and we
4 saw a lot of echoes. We call them "echoes of
5 Challenger." Sally Ride coined that term one time in
6 a press conference, and it absolutely was correct. In
7 our Chapter VIII of the report we really show shuttle,
8 Challenger/Columbia, Challenger/Columbia, and show a
9 lot of significant common elements. Next slide.

10 Both accidents were failures of foresight
11 and policy compromises. By the way, you'll see
12 criticisms on both sides of Pennsylvania Avenue here.
13 Remember I said it's not just the two guys that didn't
14 chlorinate the well, you know, it dated back all the
15 way to Parliament in Canada. We found that to be true
16 for responsibilities for the White House, Congress,
17 and NASA that dates back to multiple administrations.

18 NASA culture allowed flying with flaws
19 when problems were defined. That's that normalization
20 of deviance I talked about earlier. It appeared to be
21 immersed in a concept of invincibility. They were the
22 leading experts in the world. I mean, it's kind of
23 hard for people to come in, do a study on them, and
24 then people to accept it when you're viewing yourself
25 as the expert. We've seen this in many other

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 organizations, and I think that can be applied maybe
2 to the nuclear industry too.

3 You have to be always careful about that.
4 You have to encourage dissent points of view, and you
5 have to ask for it. You have to welcome it. And
6 unfortunately that wasn't being done. Next slide.

7 So organizational cause, history,
8 decision-making, organizational structure, system
9 effects, as well as all the words we've got here that
10 I explained a little bit earlier. The Board has great
11 confidence that the shuttle can get back to flying
12 again in the short term. We had significant less
13 confidence that the shuttle can be maintained because
14 of organizational, managerial issues for the long
15 term.

16 So we made some recommendations to try to
17 put in place that would help. You know, after the
18 tenth or fifteenth, they don't gravitate back like
19 they did after Challenger to the issues of compromise,
20 balance of power, checks and balances, safety, and so
21 forth. Next slide.

22 So the history. We have a lot of
23 compromises that were made in the original design of
24 the shuttle. Decision-making: we see problems where
25 people were saying, "Prove to me there is no problem,

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 to prove to me there is a problem." Organizational
2 structure, where we have balance of power, checks and
3 balances, and safety are not sitting at the table
4 right now. And system effects where structure and
5 managerial emphasis. They were more concerned about
6 who asked for the photo, rather than saying boy that's
7 a darned good idea, why don't we get a second opinion,
8 and prove to me there is no problem, rather than prove
9 to me there is a problem.

10 Okay, we didn't want to just leave it to
11 the point where we were guilty of just saying thank
12 you very much, and looking backwards, which is typical
13 of safety investigations. Here's the technical cause,
14 looking backwards. Here's the organizational
15 structure, looking backwards. We wanted to look
16 forward with our recommendations and say, okay, what
17 is it that we thought were absolutely essential for
18 return-to-flight?

19 We came up with 29 recommendations.
20 Fifteen were return-to-flight. In other words, those
21 are recommendations that we said NASA has to do before
22 they fly the next time. The other 14 were non-return-
23 to-flight recommendations that go into the mid-term.
24 Organizational recommendations I'll talk about in a
25 minute, and re-certification of the orbiter.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 We did call for re-certification of the
2 orbiter. We found great discontinuity between
3 specifications that were in books, like the 0.006
4 foot-pounds of pressure that could be taken by an
5 impact to the reality it can take more than that. It
6 probably can take 2, 3, 4 pounds of pressure depending
7 on angle and density and all the necessary entry, but
8 not 8,000 pounds. So make the reality of what is true
9 to be what's in the books. So it requires re-
10 certification of the orbiter.

11 It called for a national debate on manned
12 space flight. And where Congress is going through a
13 lot of hearings now. And then replacing the shuttle.
14 We call for, and these are our exact words, replace
15 the shuttle as soon as the possible as the main means
16 of manned space flight getting into low-earth orbit.

17 And we didn't say tomorrow, or next year.
18 We fully anticipate this is going to be an 8- to 10-
19 year kind of project. But do it as soon as possible
20 as the main means of getting man into low-earth orbit.
21 Next slide.

22 Now the Board recommendations, I'm not
23 going to go through all of them, but here we have
24 return-to-flight in blue, and non-return-to-flight.
25 In other words, mid-term to long-term. But we look at

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 some of these subject areas. You know, wiring and
2 bolt-catchers, and micro-meteorite and foreign object
3 damage.

4 The big one for the mishap was the thermal
5 protection. We had four for return-to-flight. That
6 was everything from you've got to fix the foam coming
7 off. They've done that. We'll never see that bipod
8 foam again. They redesigned it. You've got to
9 improve the debris that comes off. It's not just that
10 bipod. There's other debris.

11 Then when it comes off, you've got to
12 figure out how to see it with better cameras and
13 analysis, and checking. And then after you see if
14 there is a problem, then you've got to figure out how
15 to repair it. And not just against the space station.
16 The next 99 to 100 missions are going to the space
17 station. That sounds good because if you're on the
18 space station you figure well, I can do some repairs
19 and really check it out. But you might have an abort
20 to orbit and not get to the space station. So we have
21 to have a autonomous capability to do repair.

22 And then if you do get to the space
23 station you can use it as a sanctuary to maybe work
24 repairs, or God forbid you can't repair it, and then
25 you've got to bring up another orbiter. So there's a

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 lot of issues in here that we spent a lot of time on.

2 Next slide.

3 But the ones that I want to show you right
4 now are the organizational recommendations here. Now
5 this first one is clearly what I've already talked
6 about. Separate the technical assessment capability
7 from the program. And that's what this one says. A
8 technical engineering authority that was independent.

9
10 So if the program manager wants to waive
11 a specification or a requirement, he cannot do that on
12 his own or her own. They have to go to a special
13 technical assessment, they will do the analysis,
14 detailed analysis, not PowerPoint briefing, detailed
15 analysis to be able to conclude yes or no, we support
16 this.

17 So be the sole waiver authority for
18 technical standards, conduct integrated analysis,
19 trend analysis, verify, and then should be funded
20 directly from NASA headquarters independent from the
21 program, not dependent upon the program. Next slide.

22 In the next recommendation we said this
23 central safety. Again, relegate, bring safety back up
24 to where it should be, put it more centrally from the
25 headquarters. And organizations be independently

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 resourced, not dependent on the program. Program
2 safety before was funded by the program.

3 And reorganize the integration office.
4 Get away from the stovepipes. Have a true integration
5 function where you can go, the program manager can go
6 and feel confident that they have got horizontal
7 integration all the way up the line, and it's not
8 going to be stovepiped and not done in a concrete and
9 organized manner. Next slide.

10 Okay, next. Okay, we'll leave it here.
11 In the end, last thing I just want to say here is the
12 Board assumed and concluded that the U.S. wants to
13 retain the human space flight program. Now the Board
14 worked over seven months to get this report. We're
15 really into the ninth month. On Tuesday of next week,
16 we are going to release the remaining volumes, which
17 are Volumes II through VI. These are all supporting
18 the main document. We didn't accept everything in
19 there, but it's a good reference material for people
20 to understand what went into the conclusions that we
21 finally got to.

22 But our Board worked to understand the
23 causes, to minimize the risk for the future space
24 program. And as President Bush said on February 1,
25 "Mankind is led into the darkness beyond our world by

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 the inspiration of discovery and the longing to
2 understand. Our journey into space will go on."

3 Mr. Chairman, I'm prepared to answer any
4 questions that you or the Board may have.

5 CHAIRMAN CONWAY: General, I thank you
6 very, very much for a very, very excellent
7 presentation here. And your report itself is an
8 indication of a very good hard work by a lot of very
9 experienced and very capable people.

10 I will say I'm hopeful that the Department
11 of Energy and the work that it does for the safety of
12 the nuclear weapons program will have learned from
13 this because we see right today the Department of
14 Energy has undertaken what we believe to be some major
15 changes in the way they've operated in the past, and
16 as they're proposing to upgrade in the future, that
17 have this Board somewhat concerned.

18 I think there's a lot of lessons to be
19 learned here. And we hope that the DOE will have
20 learned from these studies that you and your
21 associates have put together, and to keep them from
22 making some major mistakes.

23 VICE CHAIRMAN EGGENBERGER: I'd like to
24 discuss a little bit with you the engineering
25 organization as you believe it should be. Let me talk

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701