

BEFORE THE
NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D. C.

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In the Matter of: :

THE INVESTIGATION OF THE ACCIDENT :

INVOLVING TRANS WORLD AIRLINES, INC., : VOLUME II

FLIGHT 800, B-747-131, N93119 8 MILES :

SOUTH OF EAST MORICHES, NEW YORK, :

ON JULY 17, 1996 :

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Baltimore Convention Center
Halls A and B
One West Pratt Street
Baltimore, Maryland 21201-2499

Tuesday, December 9, 1997

The above-entitled matter came on for hearing
pursuant to notice at 9:00 a.m.

BOARD OF INQUIRY:

HONORABLE JIM HALL, Chairman

Member of NTSB

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Office of Aviation Safety

BARRY SWEEDLER, Director

Office of Safety Recommendations
and Accomplishments

DAN CAMPBELL, General Counsel

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THOMAS HAUETER, Chief

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Operations

GEORGE ANDERSON

DR. MERRITT BIRKY

DR. DAN BOWER

MALCOLM BRENNER

JOHN CLARK

DENNIS CRIDER

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MITCHELL GARBER

FRANK HILLDRUP

HENRY HUGHES

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LARRY JACKSON

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DAVID MAYER

CHARLES PEREIRA

ROBERT SWAIM

BURT SIMON

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P R O C E E D I N G S

[Time Noted: 9:00 a.m.]

CHAIRMAN HALL: We will reconvene this hearing of the National Transportation Safety Board.

Unless there is anyone in the hall that wants to have a public demonstration, we will begin the business.

(No response)

CHAIRMAN HALL: Seeing no signs of screamers this morning, Mr. Dickinson, if you could please. The next Panel is Fuel Tank Design Philosophy and Certification Panel.

If you would please introduce the presenters and swear in the witnesses.

MR. DICKINSON: Good morning, Mr. Chairman.

Would the Witness Panel people please all stand up, and also Mr. Bob Swaim and Dr. Merritt Birky.

(Witness testimony continues on the next page.)

1 Whereupon,
2 ROBERT SWAIM, MERRITT BIRKY, IVOR THOMAS, JERRY HULM
3 RON HINDERBERGER, DAN CHENEY, CHRIS HARTONAS, BEATRIS
4 RODRIGUEZ and LOU TAYLOR

5 were called as witnesses on behalf of the
6 NTSB and, having been first duly sworn, were examined
7 and testified on their collective oaths as follows:

8 MR. DICKINSON: Thank you. Please be
9 seated.

10 The Fuel Tank Design Philosophy and
11 Certification Panel --

12 CHAIRMAN HALL: Just a moment. Let's
13 everyone please get to your seats, please, so that we
14 can get some quiet in the hearing room.

15 Thank you very much.

16 Please proceed.

17 MR. DICKINSON: The Fuel Tank Design
18 Philosophy and Certification Panel consists of seven
19 members in the panel, and they will be questioned by
20 Mr. Bob Swaim and Dr. Merritt Birky.

21 Bob will lead off with an opening statement.
22 The background for Bob is, he's an aircraft systems
23 investigator with the Safety Board, nine years with the
24 Safety Board. He has experience with Value Jet, DC-9
25 in Miami, Florida in 1996, U. S. Air Force flight in

1 Croatia; American Airlines Boeing 757 in Columbia; and
2 American Eagle ATR Roseland.

3 Some of his investigation experience prior to
4 joining the Safety Board, he was the Production
5 Management with Cayman Aerospace Helicopters; liaison
6 and engineer for Hughes Helicopters.

7 He also is a commercial diver and airplane
8 and aeroplane mechanic.

9 His education includes a Bachelor of
10 Industrial Education, the University of Maryland; and
11 he's an aerospace engineer and equipment, OPM.

12 Members of the Panel consist of Ivor Thomas,
13 who is the Chief Engineer of Fuel Systems and Auxiliary
14 Power Units with the Boeing Commercial Airplane Group.
15 He has 40 years in the airplane industry, 31 at Boeing,
16 working on all types of commercial airplanes.

17 In 1974 he was designated by the Federal
18 Aviation Administration as a designated engineering
19 representation of DER, currently manages all DER's in
20 propulsion discipline, and he's an expert in field
21 systems and fire safety; and is Chairman of the Joint
22 U. S. European effort to harmonize propulsion
23 certificate requirements.

24 Jerry Hulm who is the Manager of Electrical
25 Systems with Boeing Commercial Airplane Group, and I

1 would appreciate it -- well, I guess you have your name
2 tags up there, but please raise your hand, just so the
3 audience knows you.

4 (Mr. Hulm raised his hand)

5 MR. DICKINSON: Thank you.

6 He has 16 years with Boeing involving
7 designing wire installations for the U. S. Air Force
8 tankers, and in the last 13 years, he has participated
9 in design analysis, test and certification of fuel
10 quantity indicating systems for Boeing 737, 757, 767
11 and 777.

12 Next is Mr. Ron Hinderberger.

13 (Mr. Ron Hinderberger raised his hand)

14 MR. DICKINSON: Thank you.

15 He's Director of Propulsion Production
16 Program for Engineering for Douglas Products Division,
17 the Boeing Company. He is a designated engineering
18 representative for the FAA in fuel systems. He is a
19 member of the Automotive Engineers Commercial Transport
20 and Propulsion Committee, and a past member of the SAE
21 S5A Fuel Systems Working Group.

22 Prior to the merger with Boeing, he had
23 worked 19 years with McDonnell-Douglas Corporation. He
24 has a Degree in Engineering from Parks College in St.
25 Louis University.

1 Daniel Cheney.

2 (Mr. Dan Cheney raised his hand)

3 MR. DICKINSON: Thank you.

4 Manager, FAA Seattle Aircraft Certification
5 Office, Propulsion Branch, employed with the FAA since
6 1973, and has managed propulsion systems certification
7 and end service safety oversight for civil aviation
8 products manufactured within the geographic area of the
9 Pacific Northwest since 1993.

10 He has a B.S. Degree in Aerospace Engineering
11 from California State Polytech U at Pomona, California.

12 Chris Hartonas.

13 (Mr. Chris Hastonas raised his hand)

14 MR. DICKINSON: Thank you.

15 Aerospace engineer, Federal Aviation
16 Administration. He is an engineer who graduated in
17 1981 from Ohio Northern University. He combined 16
18 years of experience and design certification of
19 electrical systems and equipment for civil and military
20 aircraft.

21 Beatris Rodriguez.

22 (Mr. Beatris Rodriguez raised her hand)

23 MR. DICKINSON: Thank you.

24 Fuel systems technical specialist,
25 Aeronautical Systems Center, Patterson Air Force

1 Base since 1993. She has assumed the duties as the
2 technical specialist in the areas of air vehicle fuel
3 systems, fuel containment, and fuel tank explosion
4 suppressant materials in the Flight Systems Engineering
5 Division.

6 Ms . Rodriguez supported the TWA 800
7 investigation by serving as the fuels systems engineer
8 for the Air Force Group that examined the wreckage at
9 Calverton.

10 And last, but not least, Mr. Lou Taylor.

11 (Mr. Lou Taylor raised his hand)

12 MR. DICKINSON: Thank you.

13 Principal engineer for the In Service
14 Reliability and Safety at Honeywell's Minneapolis Base
15 Commercial Aviation Systems, Sensor Products Operation.

16 He jointed Honeywell in 1981. During the
17 time, he has held various technical positions in
18 product engineering, customer support engineering and
19 reliability engineering.

20 Mr. Taylor holds a B. S. Degree in Aerospace
21 Engineering from the University of Minnesota, and an
22 MBA from University of Minnesota. He is a former Naval
23 aviator and received training in aircraft accident
24 investigation from the U. S. Department of
25 Transportation, Transportation Safety Institute.

1 Now, Mr. Chairman, if it's okay with you, Mr.
2 Swaim will start his introductory briefing.

3 CHAIRMAN HALL: Please proceed.

4
5 BOB SWAIM

6 Introductory Briefing

7
8 MR. SWAIM: Thank you, sir.

9 In this Panel, we will be discussing the
10 design requirements for fuel systems.

11 We will begin by asking the FAA to describe
12 the certification requirements that exist for field
13 systems.

14 As Mr. Dickinson introduced, with us are
15 representatives from the manufacturer of the airplane
16 and the maker of the fuel quantity indication system.
17 They will be discussing how their companies meet the
18 FAA certification requirements, and protect against
19 fuel tank problems.

20 A representative of Douglas is with us to
21 describe how Douglas airplanes were designed. We would
22 also like to examine the differences between newer and
23 older design methods used by the manufacturers, and Ms.
24 Rodriguez can help us with questions about military
25 field systems.

1 There have been previous accidents that
2 followed fuel tank explosions, and we would like to ask
3 a few questions regarding what if any actions followed
4 those accidents.

5 As noted during the introductions, Mr. Cheney
6 is the Manager of the FAA's Seattle Aircraft
7 Certification Office Propulsion Branch, and my first
8 question goes to Mr. Cheney.

9 Mr. Cheney, could you please explain the
10 certification requirements pertaining to volatile
11 vapors in fuel systems?

12 WITNESS CHENEY: Yes, Bob.

13
14 DAN CHENEY, FAA

15 Certification Requirements for
16 Volatile Vapors in Fuel Systems

17
18 WITNESS CHENEY: First, I would like to make
19 it very clear that our standards regarding volatile
20 vapors in fuel tanks have always assumed that the vapor
21 space is flammable, and by "flammable," I mean that if
22 an arc of sufficient energy, or a temperature greater
23 than the auto ignition temperature existed, that the
24 tank would ignite.

25 We know that that is not always the case, but

1 for the purposes of the safety evaluation, we have
2 assumed that it is always flammable, and that's been
3 essentially the basis of aviation since the first
4 airplane.

5 There are very few aircraft today that
6 operate in an environment any different than that.

7 The standards for current flammable vapor
8 requirements for civil transports really took shape in
9 the 1960s. There was a very significant accident, in
10 fact, very close to Baltimore, involving a Pan Am 707
11 that was struck by lightning on approach to
12 Philadelphia.

13 In fact, I was just reviewing the records
14 this morning, and I learned that that accident occurred
15 34 years ago yesterday.

16 The accident report indicated that the left
17 reserve tank had been struck by lightning. The tank
18 exploded, and the left wing separated. What was
19 subsequently done was, an extension review of lightning
20 criteria, a much better understanding of lightning, an
21 intensive reevaluation of the methodology for lightning
22 protection.

23 Two years after that, the Boeing Company
24 applied for type certification for the 747. So, the
25 involvement of the development of standards for

1 lightning were superimposed upon the evolution and the
2 certification of this airplane. The policies that were
3 developed were actually applied initially to this 747
4 airplane.

5 The two specific regulations that currently
6 address the vapor space were originated in the Sixties,
7 in 1967. The certification basis of the 747 was
8 predicated upon a Federal Aviation regulation of the
9 1965 version, plus some special conditions.

10 One of those special conditions was,
11 lightning protection of the vapor space. It was
12 Propulsion Special Condition 15. The criteria that was
13 initially contained in the special condition became
14 finally finalized in an FAR, it's FAR 25954, which
15 currently contains the lightning criteria.

16 There was a companion advisory circular - and
17 for those that aren't familiar with the advisory
18 circulars - they are publications that the Federation
19 Aviation Administration develops in coordination with
20 industry, that gives guidelines on how compliance is
21 found with certain regulations.

22 CHAIRMAN HALL: It would help, too, if you
23 would explain, since we do have a number of people
24 watching these proceedings, of what an FAR is and the
25 difference between an FAR and a directive.

1 WITNESS CHENEY: Okay. The Federal Aviation
2 Regulations, the FAR, the rules, the requirements, if
3 you will, by which the aircraft are certified. In the
4 case of transport airplanes, the relevant FAR is FAR
5 Part 25. It contains all of the safety requirements,
6 performance requirements for transport airplanes.

7 It has evolved throughout time, through many,
8 many years. It's still evolving. It's constantly
9 being changed.

10 Then the version of the rules applied to the
11 747, as I mentioned, were 1965 version, plus special
12 conditions . They were developed simultaneously with
13 the two criteria that were applied to vapor safety.

14 One addressed the external threat, and this
15 at the time, was very much focused on lightning in the
16 aftermath of the Elkton, Maryland, Pan Am accident.
17 The second was the internal threat, and that internal
18 threat was primarily concerning the temperature of in
19 tank components.

20 That rule finally was issued in 1967, and
21 it's Part 25.981, and it has to do with tank
22 temperature criteria. It's essentially the regulation
23 that ultimately describes what "explosion-proof" means.

24 The Advisory Circular was also issued at
25 about that same time, that also describes the criteria

1 by which you ultimately determine explosion-proofness.

2 Those two concepts, the lightning protection
3 for external threats, the internal explosion-proof
4 criteria for internal threats, form the basis for vapor
5 safety in transport airplanes.

6 Now, that is not to say that in the future,
7 if we are able to attack this problem from a second
8 level, if we are able to attack the flammability of the
9 other space successfully, and we were able to achieve
10 that on transport airplanes across the board, I would
11 very much resist backing off on any vigilance for in-
12 tank ignition.

13 I think we must, if we are able to achieve
14 that, we must retain both levels of protection:
15 freedom of ignition, as well as, if we aren't able to
16 achieve freedom of flammable vapor, maintain both of
17 those in the future.

18 MR. SWAIM: Very good. I sure appreciate
19 that.

20 If it is decided to change those regulations,
21 are they mired or are they flexible? Can the
22 regulations be changed fairly readily?

23 WITNESS CHENEY: Well, the regulations are a
24 process that the people have a great hand in
25 developing, and there is not any regulation that isn't

1 put forward for full public debate, full public
2 comment.

3 One of those areas would have to be, is it
4 technically achievable? Is it practical? Will it
5 work? Will it keep air commerce where it needs to be?
6 so, if those challenges are met, it certainly is very
7 possible to change the regulations.

8 MR. SWAIM: Okay. Thank you.

9 Mr. Thomas, what does Boeing do in excess of
10 the FAA requirements for fuel tank safety? Can you
11 introduce us to what is in the center tank?

12 WITNESS THOMAS: Yes, I can certainly try to
13 do that, Mr. Swaim.

14 Is it proper at this time I give a
15 presentation, or just go through the questions.

16 MR. SWAIM: Yes. If you have some graphs and
17 would like to show the basics that way, that would be
18 fine .

19 WITNESS THOMAS: Okay. I'll do that then.

20

21 IVOR THOMAS, Boeing

22 Fuel Tank Safety

23

24 (Slide)

25 WITNESS THOMAS: The first slide is a very

1 simple system that I designed.

2 CHAIRMAN HALL: Mr. Thomas, if you could just
3 get that microphone. You will have to get real close
4 to it --

5 WITNESS THOMAS: Okay. Excuse me.

6 CHAIRMAN HALL: -- for everybody to hear
7 well.

8 WITNESS THOMAS: Is that better?

9 CHAIRMAN HALL: That's fine.

10 WITNESS THOMAS: Thank you.

11 The first slide is a very simple statement of
12 our design philosophy of fuel systems, and it really
13 goes along directly with what Mr. Cheney has just said.
14 We preclude ignition sources from the fuel tanks by
15 ensuring the no surface temperature or energy source
16 that could ignite the fuel and mixture could exist in
17 the system, and we do have both during normal
18 operation, and with any failure we can envisage during
19 the life of the airplane.

20 The second equally important is to provide
21 highly reliable fuel system that doesn't affect
22 airplane safety. The intent of that, obviously, is the
23 fact that we have to keep the engines running. It's
24 equally important to keep the airplane in the air
25 safely.

1 SO, we addressed both sides, both the
2 ignition, preventing ignitions in the airplane, and
3 providing a highly reliable system.

4 In more detail, as Dan again said, we assume
5 the tank ullage the air space above the fuel is
6 flammable at all times. That's a fundamental premise
7 in our design. It addresses the wide range of fuels
8 that we can be exposed to. We have airplanes that can
9 be operating in a military environment using JP-4. We
10 have other airplanes that could be operating in Russia
11 or China using their own peculiar fuels. We obviously
12 have airplanes operating all over the world in
13 commercial operation.

14 The surface temperatures inside the tanks we
15 design so that no surface temperature can go above a
16 number which is 50 degrees below the minimum
17 temperature required to ignite a fuel mixture. So, we
18 keep a 50 degree mänge (sic) in between anything we do
19 inside the fuel tanks, and that lowest temperature
20 required to ignite a fuel vapor.

21 We also ensure that electrical energy being
22 delivered into the fuel system, which is only the
23 gauging system itself, is limited and controlled to a
24 value that is ten times below the value required to
25 ignite a fuel M mixture.

1 The electrical components of wiring in the
2 fuel tanks are also subjected and tested to make sure
3 they can't break down at 1,500 volts.

4 DR. LOEB: Mr. Thomas, if it's possible, I'd
5 like to just get on the record one clarification. You
6 referred to the ignition temperature, 50 degrees below
7 the ignition temperature. You are referring to the
8 auto ignition temperature?

9 WITNESS THOMAS: Correct; surface
10 temperature, yes.

11 DR. LOEB: Could you explain that to our
12 audience, please.

13 WITNESS THOMAS: Yes, certainly, I'll try.

14 There are two means of igniting fuel vapor.
15 One is a simple spark, which we've talked about at
16 length, and will continue to talk about at length in
17 this discussion. The other one is simply a hot
18 surface. If you have something that is -- if you heat
19 up a box or a cylinder or whatever and progressively
20 heat it up inside the fuel M mixture, at some point,
21 the surface temperature of that box or cylinder will
22 become hot enough to cause the fuel vapor to ignite.

23 We refer to that as an auto ignition
24 temperature, or octagenous ignition temperature. We
25 measure the surface temperature and say when that will

1 happen. It's a function of the size of the tank. It's
2 a function of the surface area, the temperature of the
3 surface are. The testing has been done. Certainly,
4 I'm aware of going back 30 and 40 years, has
5 established a minimum number of 445, 450 degrees as the
6 lowest number you can achieve ignition at, and that's
7 in a very carefully controlled experiment.

8 We go 50 degrees below that, we use the
9 number of 390 degrees in the fuel tanks for our upper
10 limit on our fuel tanks.

11 CHAIRMAN HALL: Well let me see if I
12 understand this. Now, you're saying that 50 degrees
13 below auto ignition, not 50 degrees below a spark that
14 might ignite something?

15 WITNESS THOMAS: No. A spark is a totally
16 different creature. A spark, you can get ignition
17 anytime the fuel is flammable, and a spark has enough
18 energy.

19 CHAIRMAN HALL: And let me ask Mr. Cheney a
20 question, if I could, so I understand this: What does
21 the FAA use - and your presentation said that you
22 assumed that the tank is always flammable - what
23 temperature do you base that on, and what is an arc of
24 sufficient energy?

25 WITNESS THOMAS: Well, the flammability range

1 is ordered by a temperature below which the vapor is
2 too lean to burn, and on the upper end, too rich to
3 burn. And those are referred to as the lean limit and
4 the rich limit; and for kerosene, Jet A fuel at
5 standard pressure, that lean limit is approximately 100
6 degrees Fahrenheit.

7 SO, the assumption is, your tank is always
8 above 100 degrees. It's right in the middle of the
9 range from a safety criteria standpoint. We would
10 never allow a system to be taking credit for not being
11 flammable; in other words, if there is no safe ignition
12 in a fuel tank.

13 CHAIRMAN HALL: And what is an arc of
14 sufficient energy?

15 WITNESS THOMAS: That's an electrical
16 question that I don't have the electrical background.
17 I think it's majored in jewels, and maybe one of the --

18 CHAIRMAN HALL: Well, we've got some
19 electrical experts.

20 WITNESS HINDERBERGER: The industry standard
21 established, I believe, is 200 microjewels.

22 CHAIRMAN HALL: Micro what?

23 WITNESS HINDERBERGER: Microjewels.

24 CHAIRMAN HALL: Microjewels. All right.

25 Thank you.

1 Mr. Thomas?

2 WITNESS THOMAS: Certainly. Does that
3 satisfy your questions?

4 CHAIRMAN HALL: Yes. I just want to try to
5 understand this as we go along, because if I wait until
6 my turn, I'll be lost. So, proceed ahead.

7 WITNESS THOMAS: As I said, the electrical
8 components inside the wiring inside the fuel tank, we
9 require they not arc when subjected to a 1,500 volt AC
10 current. So, this is in effect a test to make sure
11 that no component inside the tank, if I apply a very
12 high voltage from the airplane, can cause a spark
13 inside the tank.

14 So, basically, the fundamental criteria we
15 use is, nothing inside the tank is hot enough to cause
16 an ignition, and there are no sparks inside the tank
17 that can cause an ignition. That's our fundamental
18 policy.

19 CHAIRMAN HALL: Well, I guess my last
20 question is, is that 50 degrees below a minimum
21 temperature, is that a range of temperatures, or is
22 that one specific temperature is 50 degrees below?

23 WITNESS THOMAS: Any of our surface
24 temperatures inside the fuel tank, we would keep below
25 the 390 degree number, and that is in a failure case,

1 as well. That is not normal running typically of the
2 equipment; we are running much, much, more cooler than
3 that. But in a failure case, we design it to make sure
4 we do not exceed that 390 degrees Fahrenheit.

5 MR. SWAIM: Okay. Our expert, Dr. Birky, is
6 a fire explosion group Chairman. Mr. Birky?

7 DR. BIRKY: Yes. I have a question of Mr.
8 Cheney again.

9 You referred to explosion-proof, and I'm not
10 sure what you mean by that. Could you explain that for
11 us?

12 WITNESS CHENEY: Well, the policy that was
13 developed in the Sixties and documented in the Advisory
14 Circular, gave several failure conditions for
15 components to be subjected to in a flammable medium,
16 and when in that medium, there should be no explosion.
17 And it's been referred to as a finding of explosion-
18 proofness.

19 Now, it's been referred to components, that
20 all components reside in a fuel cell, although you
21 won't find that term in the FARs or the policy
22 material, but it's used commonly in industry
23 discussions .

24 CHAIRMAN HALL: And in the Sixties, was that
25 based on Jet A fuel, or was that based on another fuel,

1 or was the fuel unimportant to that?

2 WITNESS CHENEY: Well, the fuels are very
3 important, and Jet A is a kerosene-base fuel, and it's
4 lower explosive limit is about 100 degrees. It's auto
5 ignition temperature, like Ivor was saying, is about
6 450 degrees.

7 Other types of fuel, such as JP-4, has an
8 auto ignition temperature much higher than Jet-A. It's
9 in the range of 800 degrees Fahrenheit. So, there is
10 quite a difference in the way in which fuel behaves.

11 DR. BIRKY: Mr. Cheney, may I also hop in
12 here? I'm not clear.

13 You're saying JP-4 has an auto ignition
14 temperature above Jet-A?

15 WITNESS CHENEY: That's what is contained in
16 Advisory material. That's what is written.

17 DR. BIRKY: My reference material, I think,
18 from a chemistry point of view, they aren't going to be
19 much different than auto ignition temperature, but
20 certainly, the flash points will be different; is that
21 correct?

22 WITNESS CHENEY: What I am discussing is what
23 is contained in the Advisory material that was
24 published in the Sixties, and it's still current.

25 DR. BIRKY: Okay. But I'd like to go back to

1 this question of explosion-proof. Are you suggesting
2 that the FAR 25.981 does not refer to explosion-proof,
3 or it does? I'm not sure.

4 WITNESS CHENEY: That term is not included in
5 the FAR. What the FAR requires is two parts: One for
6 the constructor to establish what is the auto ignition
7 temperature of the most critical fuel that they plan to
8 use in that vehicle; and secondly, assure that in every
9 conceivable failure case, that you leave an adequate
10 margin of temperature away from that auto ignition
11 temperature.

12 It's a two-part process. The Advisor
13 material details on how that is accomplished.

14 DR. BIRKY: So, the explosion-proof then
15 refers to the electrical equipment and other sources of
16 ignition inside; is that correct?

17 WITNESS CHENEY: That's correct.

18 DR. LOEB: I'd like to just clarify for the
19 record: The 50 degrees that you're referring to, the
20 50 degrees below the auto ignition temperature, that is
21 in the Advisory Circular and not in the rules?

22 WITNESS CHENEY: That's correct, it is in the
23 Advisory material.

24 DR. LOEB: Okay. Thank you.

25 MR. SWAIM: That then would not refer to,

1 say, the bottom of the fuel tank located above the air-
2 conditioning machinery?

3 WITNESS CHENEY: It would refer to anything
4 inside the fuel tank that can communicate with vapor,
5 any surface.

6 MR. SWAIM: But my point is, including the
7 field tank itself?

8 WITNESS CHENEY: Yes.

9 MR. SWAIM: Okay.

10 DR. LOEB: Excuse me. One more
11 clarification: In this case, is that Advisory Circular
12 and the 50 degrees that is in the Advisory Circular, is
13 that a requirement now by somehow referencing the
14 Advisory Circular to the rule, or in some other
15 mechanism, or is it simply Advisory?

16 WITNESS CHENEY: It is Advisory. It's used
17 as an industry practice today, and it's been in place
18 since 1967 and essentially unchanged. It's still a
19 current policy that is used on today's projects.

20 DR. LOEB: But it is not a requirement?

21 WITNESS CHENEY: It's not a requirement.

22 CHAIRMAN HALL: Please proceed, Mr. Thomas.

23 WITNESS CHENEY: Thank you, sir.

24 CHAIRMAN HALL: And if you will just indulge
25 us on this because this is an important area, and I

1 want to be sure that all understand it, those at the
2 top of the expert level, and those who are just down
3 where I am.

4 WITNESS THOMAS: Thank you. Please feel free
5 to interrupt. I really want you to understand what is
6 this issue. It's very important.

7 The last bullet on this slide is an important
8 one, and that is, we try and make sure, very carefully,
9 that failure that could affect the airplane safety are
10 announced through some mechanism, either to the pilots
11 or to the crew during a walk-around, or to mechanics
12 doing maintenance activities.

13 SO, we place a very high emphasis on ensuring
14 the failures are detectable, and where we see a latent
15 failure, as reported from the fleet, we look very
16 carefully at that latent failure to determine is it a
17 safety issue? And if it is, then we take some
18 immediate action to resolve that, those kinds of latent
19 failures.

20 MR. SWAIM: Can you explain what a latent
21 failure is?

22 WITNESS THOMAS: Excuse me. A latent failure
23 is a failure that is not obvious, but in the
24 performance of the airplane if something occurs in the
25 sense of, it is not detected, and therefore, can be

1 present in the airplane at length, it would show up in
2 a maintenance activity later on.

3 And we try to avoid those specifically. We
4 don't want a failure in the airplane that's been in the
5 airplane a long time, if it is a safety failing. If
6 it's a light bulb, then you're not going to worry about
7 it. If it's a potential problem in a boost bump, then
8 you would want to know about it immediately; the logic
9 between the difference between a latent failure and a
10 failure that's announced through some kind of warning
11 device, or through some light, or some crew action.

12 In the engine feed system, we are using this
13 word "explosion-proof, " and I have a diagram which I
14 will use in a minute to explain this. The pumps are
15 qualified to be explosion-proof in the engine feed
16 system. We provide a lot of redundancy to keep the
17 engines running. We provide suction feed capability in
18 case of an all electrical failure.

19 To provide redundant means to shut off the
20 fuel to the engine. An engine fuel fire unto itself is
21 a safety hazard to the airplane. We make sure we have
22 the ability to shut off the fuel to the engine under
23 those kinds of circumstances.

24 CHAIRMAN HALL: Could I go back to your
25 previous slide just for one quick question.

1 It says "Electrical components in wiring in
2 the fuel tanks shall not break down our arc when
3 subjected to 1,500 volts."

4 What electrical components or wiring would
5 carry 1,500 volts?

6 WITNESS THOMAS: There is nothing on the
7 airplane that would carry that, and that really is the
8 point we're trying to make here. Normal voltages on
9 the airplane are either 28 volts or 115 volts. There
10 are some circuits that may go up as high as 200 volts,
11 or thereabouts.

12 I'm not an electrical engineer. So, we are
13 in effect, testing these things to make sure they don't
14 arc a significant margin above what is available on the
15 airplane, and that's the important point to us, that
16 the system will not arc under those circumstances.

17 CHAIRMAN HALL: Would I know if I was working
18 on the airplane, what components might present that
19 problem of an arc?

20 WITNESS THOMAS: I'm not sure I quite
21 understand the question.

22 CHAIRMAN HALL: Well, I'll get into it later.
23 I have a specific question, but I will wait until later
24 on. Thank you.

25 MR. SWAIM: From something that Mr. Thomas

1 brought up on temperatures, I have a question. Back to
2 Mr. Cheney: For the tape temperatures, you were
3 referring to a maximum temperature that you would
4 permit.

5 Would that include a failure condition, such
6 as a fire on the rear spar or the rear wall of the fuel
7 tank in the landing gear bay? How far does that go as
8 far as the limits of that regulation?

9 WITNESS CHENEY: Well, if there was an area
10 that could be subject to a fire, then that would be a
11 design consideration. There shouldn't be a fire zone,
12 if you will, adjacent to a fuel tank. What you just
13 described is a zone that would be containing a fire,
14 and in the case of the landing gear, if the gear were
15 on fire, I think the procedure is to extend the gear.

16 MR. SWAIM: Okay.

17 WITNESS CHENEY: But, I would like to clarify
18 for the record, Dr. Birky, the numbers that I gave you,
19 you are correct. The JP-4 and Jet-A, auto ignition
20 temperatures, are roughly the same. What I was
21 referring to was gasoline at about 800 degrees. So, my
22 apologies.

23 MR. SWAIM: Mr. Thomas, we keep cutting you
24 off.

25 WITNESS THOMAS: Let me continue.

1 This is a very simplistic diagram of a fuel
2 system. What you're looking at is basically a plan
3 view looking down on top of the airplane, or from on
4 top of the airplane, showing a left main tank, a right
5 main tank, and a center tank.

6 On all of our airplanes are designs. We have
7 a specific tank that feeds a given engine, so in a
8 four-engine airplane, you have main tank 1, main tank
9 2, et cetera. On a twin, it will be either 1 or 2 or
10 left and right.

11 In the main tank you have two boost pumps
12 that provide fuel to the engine. Both of those boost
13 pumps are supplied from different electrical power in
14 the airplane, so again, if we lose an electrical power
15 system, the other pump will keep running.

16 In the remote case, we lost all electrical
17 power on the airplane. There is a suction bypass which
18 allows the engine itself to suck fuel from the tank and
19 keep running. The engine shut off valve, you can see
20 down in the bottom left corner, that we use to shut our
21 field to the engine in the event of a fire, and again,
22 we have a redundant means of closing that valve,
23 various signals from the shut off valve, an engine shut
24 off switch itself on the aisle stand.

25 When you pull the fire handle, both of those

1 signals drive the valve to a closed position. The
2 override pumps in the center wing tank, we talk about
3 override pumps as being equipment in the center tank.
4 Those pumps are designed to provide fuel to the engine
5 when you are burning fuel from the center wing tank.

6 They are a size so that the pressure from
7 those pumps are actually higher by 15 or 20 psi than
8 the boost pumps themselves. So, basically, what
9 happens is, you pressurize the engine feed line, you
10 back pressure the boost pumps in the main tank, and
11 supply fuel from the center tank to the engine.

12 As the fuel runs out in the center wing tank,
13 the pumps drop pressure. Obviously, they have nothing
14 to flow any more, and the boost pumps take over
15 automatically. So, you turn the pumps on when the
16 center tank runs out of fuel, and you get a low
17 pressure warning lights. You turn the pumps off in the
18 center wing tank, and the engine continues to run from
19 the main tank.

20 so, it's a very simple, very reliable system.
21 If I show this, a 747, it would look a lot more
22 complicated because you're dealing with four engines
23 and four fuel tanks, but it's simplest in the simplest
24 way. It's a very, very similar system.

25 There is a cross feed valve in the middle of

1 the airplane that allows you to feed fuel from one side
2 to another, first of all, to balance the airplane. If
3 one engine is using fuel slightly more than the other
4 one, you can open the cross revalve and balance the
5 airplane that way, feed fuel from one side across the
6 airplane to the other engine to balance the airplane.

7 Obviously, in the case where you lost an
8 engine, you could supply fuel from, say, the left tank
9 across to the right engine to keep the airplane going
10 under those circumstances.

11 You can go to the next one.

12 (Slide)

13 WITNESS THOMAS: This is a very simple
14 schematic of a boost pump. We talked about explosion-
15 proofing. Let me talk you through this. You have an
16 impeller that is sucking fuel from the tank through a
17 line. That impeller pressurizes the fuel tank fuel,
18 and the fuel is then delivered to the engine.

19 It's a simple impeller. Some of them look
20 like the kind you have in a vacuum cleaner. Some of
21 them more like a propeller of an airplane. There are
22 mixed designs in that.

23 The motor that drives that impeller is
24 contained in a chamber unto itself, and the design of
25 that is to make sure that that chamber is explosion-

1 proof. We have used the term "explosive-proof." This
2 is a chamber where the motor is setting, but it's
3 designed specifically. If there was an electrical
4 failure in the motor that could ignite the fuel vapor
5 in that chamber, the explosion itself is contained.
6 The chamber is strong enough to contain the explosion.

7 There is no way for any kind of flame to
8 propagate from that chamber into the tank. If YOU look
9 at the drawing, you have two small passageways shown,
10 one of which is bringing fuel into the motor housing,
11 and another one returning fuel back to the tank.

12 The intent of that is to just cool the motor
13 and to lubricate the bearings, but when we design and
14 test the pump, we make sure that those passageways are
15 small enough, the flame cannot propagate down these
16 passageways.

17 There is a technology called flame arresting
18 where, if you have the tubes small enough, the flame
19 will actually quench as it tries to go down the tube
20 and go out. So, fundamentally, we design the motor
21 housing to the explosion-proof, and we test it in
22 multiple ways, and the process of testing, as Dan
23 described earlier, we in fact have the pump in a test
24 chamber where the test chamber is in fact filled with
25 explosive vapor.

1 We allow explosive vapor into the motor
2 housing, and then deliberately introduce a spark, and
3 explode that mixture in that housing, and demonstrate
4 that the flame doesn't propagate into the test chamber,
5 and then we subsequently ignite the mixture in the test
6 chamber, to prove that it really was ignitable. So,
7 it's a back-to-back test, and we repeat that test
8 several times at different temperatures, as high as a
9 hundred -- I want to say 160 degrees is the highest
10 chamber temperature we use to do that.

11 CHAIRMAN HALL: What's the lowest?

12 WITNESS THOMAS: I think it would probably go
13 down to 130. Well, we run some tests at ambient, but
14 when we are demonstrating explosion-proof testing, then
15 we will go up to 160.

16 The other thing on the diagram you can see,
17 we have temperature fuses on the motors. Those fuses
18 are non-resettable fuses intended to protect the system
19 if the motor misbehaves or starts overheating. Those
20 temperatures fuses typically at 275 degrees Fahrenheit.

21 Those fuses will open and remove electricity
22 from the pump. We demonstrate that in qualification by
23 various tasks we do, the lock rotor testing where we
24 physically just reach in there and hold the shaft and
25 turn the power on to the pump, and just watch what

1 happens.

2 We will do that in an explosive atmosphere,
3 sometimes . Sometimes, we will measure the temperatures
4 to make sure, go back to the surface temperatures to
5 make sure the surface temperatures don't exceed the 390
6 degrees. We use the thermal fuses, the temperature
7 fuses to shut off electricity to the pump under those
8 circumstances .

9 The other thing shown on here is the pressure
10 switch, which is monitoring the performance of the
11 pump.

12 You can go to the next slide, Derrick.

13 (Slide)

14 WITNESS THOMAS: This a very simplistic
15 mechanical engineer's view of electricity. You have
16 the pump, you have a power supply to the pump through a
17 circuit breaker, through a flight deck switch that runs
18 the pump. The pressure switch itself is in a
19 completely separate circuit supplied by a different
20 power supply that runs the lower pressure warning
21 light. So, basically, if you turn the pump on, the
22 pump pressurizes itself, this pressure switch actuates,
23 the light goes out.

24 If the pump fails for whatever reason, the
25 pressure will drop. The light comes on. The crew

1 knows about it immediately. Or if the circuit breaker
2 pops, the light will come on, and the crew knows about
3 it immediately.

4 Moving on looking in the tank, this is an
5 overview of the center wing tank. We have seen it
6 several times yesterday. This is just to point out
7 where the fuel quantity indicating system components
8 are located. The gentleman from Honeywell, Mr. Taylor,
9 is going to talk about this in a minute. So, I won't
10 dwell on that subject at this point.

11 The next slide, Derrick.

12 (Slide)

13 WITNESS THOMAS: The vent system, the typical
14 airplane is shown here. Again, in our philosophy of
15 trying to make things as simple as possible where we
16 have things in the airplane that are going to be there
17 for a long time, the tank vent system consists of a
18 tube that runs from the top of the input corner of the
19 tank outwards to the wing tip. If you look at the left
20 tank, you can see the tube there.

21 In actuality, in the Boeing practice, we use
22 vent stringers, actually specific structural members
23 inside the fuel tank to provide those by passageway.
24 The fuel vent system allows the tank to breathe as the
25 airplane climbs and dives. We try to keep the tank

1 close to atmospheric pressure, so as the pressure in
2 the atmosphere, we need to vent air in and out. We do
3 that through the vent system.

4 All the tanks are connected to search tanks
5 1, the site of the airplane, and then from there, you
6 breathe, the tanks breathe overboard through a flame
7 arrester, and there was a question earlier that Mr.
8 Swaim asked us, things we do over and above the
9 requirements .

10 The flame arrester is a good example of that
11 where we provide the flame arrester for ground fire
12 protection on all our later airplanes, and that is
13 something that is not required by the regulations; it's
14 something we do as a safety feature we felt was
15 appropriate to build into our later airplanes.

16 I've talked a lot about this already. Al l
17 our components in the systems, we either analyze them
18 and test them for safety. We test them for the
19 operating environment, which in our case is from sea
20 level to 43,000 feet, and from minus 65 up to 135 fuel
21 temperature, 160 ambient temperature. We look at the
22 performance of the equipment. We look at reliability
23 of the equipment.

24 We have a lot of long-term endurance testing
25 on pumps to make sure they will run and be extremely

1 reliable.

2 CHAIRMAN HALL: How long is a pump supposed
3 to last?

4 WITNESS THOMAS: Typically, a pump will last
5 30,000 hours, 35,000 hours.

6 When we are qualifying and testing, we start
7 off at the low level with component testing. We test
8 the pump. We test the valve. We put it together as a
9 system. We do those kinds of system testing. We
10 eventually get the first airplane. We do a significant
11 amount of ground testing on that airplane, and then we
12 go into flight testing to prove the system in flight.

13 All of those tests we perform for ourselves,
14 and we also invite the FAA to participate to witness
15 those tests to make sure they understand. There are
16 some parts of the test that we do for our own
17 reliability capability. Other tests are very specific
18 to satisfy the FAA, and at that time, we will invite
19 the FAA to witness those tests either directly or
20 through the use of the DERs.

21 CHAIRMAN HALL: You might explain what a DER
22 is, since we had someone introduced as one of those.

23 WITNESS THOMAS: I think there are at least
24 two or three of us on the panel here. A DER is a
25 Designated Engineering Representative of the FAA. It

1 is an employee of, in this case, if I speak about
2 myself as a DER, I'm an employee of the Boeing Company.
3 The FAA, through exposure to myself when I go down and
4 discuss issues with the FAA, get to the point where
5 they feel they can trust me and rely on my judgment.

6 They will at that point allow me to become a
7 -- nominate me as a DER. With that authority, and Dan
8 can speak of this a lot better than I can, maybe, I'm
9 allowed under certain circumstances to make such
10 judgments.

11 CHAIRMAN HALL: I appreciate that
12 explanation.

13 WITNESS THOMAS: One point, to conclude my
14 presentation, the last bullet talks to continued
15 airworthiness . This, we see, as an extremely part of
16 how we look after the airplane and maintain its safety.
17 We're in daily communication with the airlines; we're
18 in daily communication with the FAA.

19 We have something like 1,000 engineers who do
20 nothing but monitor traffic, communication traffic,
21 between ourselves the airlines. We have engineers out
22 with all the major airlines all over the world. Any
23 kind of problem, it is reported back, gets looked at
24 very quickly and very carefully to say if it's a safety
25 issue, or is it just another small problem that we

1 don't have to worry about. We can go fix for the
2 airlines in an economic fashion as opposed to a safety
3 fashion.

4 Any specific safety issue, we are required to
5 report those to the FAA very quickly. We're not doing
6 this in a vacuum. If we see a problem, we report it to
7 the FAA so that we, the airlines and the FAA can all
8 join in in resolving those problems, and we do
9 obviously continuous product enhancements as we see the
10 need, both by the economic and competition. This is a
11 competitive business we are in, and so we are
12 continuously enhancing our products.

13 And the airlines provide maintenance of the
14 airplanes throughout the life of the airplane. We
15 provide them with a lot of help in understanding how to
16 maintain our airplanes. They, in turn, create their
17 own maintenance practices to look after the airplane;
18 but through the communication back and forth between
19 the airlines and ourselves and the FAA, we keep a very
20 close watch on any problems when they show up.

21 That concludes my presentation part of this.

22 MR. SWAIM: Thank you, Mr. Thomas. Most
23 informative .

24 Mr. Hinderberger, we heard from Mr. Cheney
25 that the vapors are considered flammable, and from Mr.

1 Thomas, the basics of what Boeing does. Since you have
2 been with Douglas, now a Division of Boeing, can you
3 explain to us the certification process or designer
4 requirements that have been used by Douglas for the
5 Douglas airplanes?

6 WITNESS HINDERBERGER: Yes, Mr. Swaim.

7
8 RON HINDERBERGER, Douglas

9 Certification Process

10
11 WITNESS HINDERBERGER: One of the things that
12 I guess I wanted to point out first of all, is that
13 since the merger between McDonnell-Douglas and Boeing
14 was completed on August 1st, we have only been able to
15 have a series of discussions at a very top level to
16 discuss our relative design philosophies.

17 In those areas we found that basically, our
18 standards by which we design and certify our fuel
19 systems are basically very much the same as what was
20 done by Boeing in Seattle. The points that were
21 brought up earlier by Mr. Cheney and by Mr. Thomas as
22 it would pertain to lightning strike and ground fires
23 were indeed also incorporated on the Douglas products
24 over the years by the use of flame arresters, and by
25 the use of considering the wing tip zones as being

1 prone to lightning strikes and inclement weather.

2 Design philosophy over a period of time, I
3 would have to say, is more a function of updating one's
4 design as time goes on, as we have mentioned earlier,
5 with our experience with the 707 in the Philadelphia
6 accident.

7 What we have done is basically the same
8 things that were done by Boeing in Seattle by
9 incorporating flame arresters and that type of thing.

10 MR. SWAIM: SO, when you find an ignition
11 problem, basically a remediator will take care of that
12 one, and see what you can learn from that and move on?

13 WITNESS HINDERBERGER: Oh, absolutely,
14 absolutely. Basic design philosophy at Douglas, for as
15 long as I can remember and even before my time at
16 Douglas, has always been one in which ignition sources
17 were precluded from occurring within the fuel tank. We
18 have always assumed that for the purpose of analyzing
19 our fuel tanks for safety, that we have assumed that
20 there be a flammable mixture in the fuel tank at all
21 times, and precluded ignition sources from occurring
22 within the tank.

23 MR. SWAIM: Okay. Is there any difference
24 between the older airplanes and the new airplanes, for
25 instance, the older DC-9S versus the new MB-11S?

1 WITNESS HINDERBERGER: Well, the differences
2 between the older designs and the newer designs are
3 really basically in areas, number one that we have
4 already touched on, the use of flame arrester and the
5 use of consideration for lightning strikes.

6 One of the other areas is really one of a
7 matter of technology. Our later airplanes incorporate
8 software into the control and display of our systems in
9 the airplane, and we've had to accommodate for that
10 software in terms of testing and design standards, and
11 that's basically been documented well with the DL-178
12 regulations .

13 CHAIRMAN HALL: Mr. Swaim, can I inject this
14 one more time, and ask one basic question of both you
15 and Ivor?

16 MR. SWAIM: Of course.

17 CHAIRMAN HALL: Why did you design with the
18 assumption that there are flammable vapors? Is that
19 because of the FAA certification, or what drove that?
20 Why did you not try to then design the vapors out in
21 the Sixties?

22 WITNESS HINDERBERGER: Chairman Hall, it was
23 one basic design philosophy, and it was looked at from
24 a standpoint that what we would do is, assume that
25 there is a flammable mixture at all times. If you

1 assume there is a flammable mixture at all times, then
2 you must also preclude a spark from occurring at all
3 times.

4 so, in other words, it was one in which we
5 didn't look at a situation and say, "Well, there may
6 not be -- there should not be a flammable mixture at
7 this point in time; therefore, we can relax our
8 requirements for ignition sources within a tank."

9 It was actually just the opposite. Assume
10 that there is a final flammable in the tank; preclude
11 ignition sources at all times.

12 CHAIRMAN HALL: I understand that, but at the
13 time you all were doing all that work on figuring out
14 that design philosophy, was anyone working on the
15 philosophy of doing something about the flammable
16 mixture?

17 WITNESS HINDERBERGER: No, sir, not that I'm
18 aware of.

19 WITNESS THOMAS: If I may add, Mr. Chairman,
20 that certainly, in the Sixties the U. S. Air Force were
21 operating the JB-4, which has a very low flammability,
22 low limits, and most of our airplanes are designed or
23 are treated on the assumption of some point they would
24 be operating in an Air Force environment.

25 The 707 became the Awax (sic) . We have a 767

1 Awax in operation right now. The C-9 is the
2 Nightingale. So, there's a lot of airplanes that go
3 into military service from the commercial world. And
4 so, treating the tank as if its flammable at all times
5 allowed us to design for any kind of fuel.

6 JP-4 is a flash point down at some number,
7 like mine is 20. The Russian fuels, Chinese fuels have
8 flash points at around the 80 degrees. Our current
9 Jet-A are the ones with flash point around about 100
10 degrees. So, we had to design our airplanes to address
11 a wide range of fuels around the world, and that was
12 one of the issues.

13 It was logical to assume that it was
14 flammable at all times, and to make sure we excluded
15 the ignition source.

16 CHAIRMAN HALL: Were you all working on the
17 flammability as well, or not, or was that -- I'm just
18 trying to understand because I know that there was a
19 succession of fuels. I guess you went from AB gas to -
20 what - JP-4, and then to Jet A. Now, I guess the
21 Military uses JP-5.

22 WITNESS THOMAS: The Navy uses JP-5. They
23 had a very specific need for JP-5, which was the high
24 temperatures, as I understand it. I'm not a Navy
25 pilot.

1 CHAIRMAN HALL: When we get to the Military
2 person, I would be interested, as well.

3 WITNESS THOMAS: It's my understanding, at
4 least in conversation with Navy personnel, that the
5 issue was the very high temperatures of the hangar
6 decks of carriers. The temperatures in the hangar
7 decks can be significantly above 100 degrees. They
8 were concerned.

9 They wanted a fuel they could have on board
10 the carrier, and they went to a JP-5 fuel specifically
11 for that reason.

12 CHAIRMAN HALL: Okay. But there's really
13 been no basic need, you felt, in terms of your problem
14 resolution that you've had in place for 30 years since
15 the Sixties to address the flammability of the basic
16 assumption that you designed your center tanks around,
17 or your fuel tanks around.

18 WITNESS THOMAS: That's correct.

19 CHAIRMAN HALL: Okay.

20 DR. BIRKY: May I ask a question here of Mr.
21 Thomas . Are there problems with going to a less
22 volatile fuel to reduce that flammability issue in
23 terms of going to a lower vapor pressure fuel?

24 WITNESS THOMAS: There are issues. I'm not
25 sure I can categorize them as problems. There are

1 questions that we need to resolve. Again, it's going
2 to a higher flash point fuel like the JP-5 kinds of
3 fuel, you have to worry about all the properties of the
4 fuel .

5 There is concern in terms of making sure that
6 the freeze point of the fuel doesn't climb. One of our
7 issues, we fly the airplanes extremely long distances
8 these days, and we need to make sure that the fuel
9 itself doesn't freeze on those long flights. We need
10 to control the freeze point of the fuel.

11 There is a question in terms of the viscosity
12 at lower temperatures of how well the engines will re-
13 light with very low temperature JP-5. I'm an engine
14 expert, although I've been in the propulsion business
15 for a long time in terms of the airplane side of the
16 house; but we have engaged in conversation with the
17 major engine companies to try and understand these
18 issues. That work is already started.

19 We try and understand the issues associated
20 with using high flash point fuel.

21 DR. BIRKY: Perhaps our Air Force people can
22 answer that for question here, whether there is an
23 issue, a fundamental issue about using a lower volatile
24 fuel to reduce the flammability of the vapors.

25 Ms . Rodriguez, thank you.

1 MS . RODRIGUEZ: Yes. Not going into all the
2 details about the flight tests that we have conducted,
3 we conducted flight tests and ground tests with JP-A,
4 which we consider a low volatile fuel at that time in
5 the Eighties when we were going, a transition from JP-4
6 to JP-A. We conducted substantial ground tests and
7 flight tests and there was demonstration in the Alaska
8 base, and we did experience some problems, ground
9 starting problems with the engine and APU on some of
10 our older aircraft.

11 At that time, we implemented some changes,
12 and also some ground support. You might have to
13 precondition your engines, your APU components at
14 certain low temperatures for ground test operations.

15 Yes?

16 MR. SWAIM: Excuse me. Have you done testing
17 with the Navy's JP-5, the next step?

18 MS . RODRIGUEZ: Navy JP-5, I believe -- I'm
19 not a Navy person; I'm an Air Force person. JP-5 is
20 used in carriers. The flash point, I believe, is 140
21 degrees versus 100 degrees for JP-8. JP-5 - let me
22 check. The freezing point of JP-5 is still minus 41 --
23 minus 51, according to my records.

24 So, basically, once we start having problems
25 with our freezing points below 40 degrees for pump

1 performance, so the Navy uses JP-A on land bases, so
2 the Navy people will have a mixture. Their aircraft is
3 using JP-5 in carrier, and land using JP-A. Basically,
4 JP-A is a common fuel for only military aircraft.

5 MR. SWAIM: For reference, I think JP-8 is
6 the same as Jet A that we have been talking about here
7 quite a bit, so just for the reference point here.

8 MS . RODRIGUEZ: JP-A is mainly Jet-A1,
9 according to my records, due to the freezing point.
10 Jet-A1 is in the minus 50 degrees for military
11 additives . We add military additive for our missions.

12 DR. LOEB: I'd like to go back, if I could
13 just for a second, to Ivor or Ron, and follow-up on a
14 question that the Chairman was asking, and that is
15 whether this flammability situation was looked at for
16 means, whatever solution regardless of whether it's
17 fuel or any other type of solution.

18 Following the Philippines 737 accident, did
19 either Douglas or Boeing go back and re-examine this
20 notion given that we now had an aircraft that had blown
21 up as a result of a fuel air explosion in the tank and
22 ignition source within the tank that shouldn't have
23 existed?

24 WITNESS THOMAS: As far as the Philippines
25 737 accident, we spent a large amount of time looking

1 at potential ignition sources. There was no ignition
2 source established to cause that accident. We spent a
3 lot of time and energy looking at -- I think we looked
4 at well over 70 different potential ignition sources.

5 At that time, we did not address the
6 flammability issue as far as the tank itself was
7 concerned. We were still using our fundamental
8 philosophy of the tank could be flammable at all times,
9 and we had to find the ignition source and correct it.
10 In that particular case, we were unable to establish a
11 specific ignition cause for that accident.

12 DR. LOEB: Well, the Board determined the
13 possibility of an ignition source; however, what we did
14 eliminate was auto ignition or any external source of
15 ignition. Therefore, the notion that ignition sources
16 had been engineered out was not the case, in other
17 words, in that particular accident.

18 So that's why I'm raising the question, did
19 either Boeing or Douglas re-examine that notion and
20 attempt to address the flammability? And I guess
21 you're saying, Mr. Thomas, that Boeing did not.

22 WITNESS THOMAS: That is correct.

23 DR. LOEB: Mr. Hinderberger, did Douglas do
24 anything?

25 WITNESS HINDERBERGER: No, sir, Dr. Loeb, we

1 did not.

2 DR. LOEB: Mr. Cheney, did the FAA take a
3 look at that issue following the Philippines 737?

4 WITNESS CHENEY: Well, we were a party to the
5 investigation, and the components in that accident were
6 extensively tested, and there was no evidence of any
7 ignition source found. But I would like to add that in
8 the information that's been gained in the investigation
9 of this accident, we are reopening that accident and
10 re-evaluating specifically the recommendations that
11 were made, and re-assessing the design of the 737 in
12 light of the design of the 747.

13 DR. LOEB: In light of the fact that no
14 ignition source was conclusively established in the
15 Philippines accident, wouldn't that raise concerns
16 about the notion that the ignition sources had been
17 engineered out, since something ignited the fuel air
18 vapors, but it was never conclusively determined what?

19 WITNESS CHENEY: That's right. Something
20 ignited that tank.

21 DR. LOEB: But would that not raise a
22 question about the validity of the concept, if we were
23 not even able to conclusively determine what ignited --

24 WITNESS CHENEY: And I think, as the
25 Administrator mentioned in the letter the other day to

1 the Board, we are agreeing with the Board that it is
2 very appropriate to very much explore reducing or
3 eliminating flammable vapors in tanks.

4 DR. LOEB: Good. Thanks .

5 CHAIRMAN HALL: I would like to ask Mr.
6 Thomas one question before we move on.

7 Mr. Thomas, what has Boeing done since the
8 TWA-800 accident to address this issue?

9 WITNESS THOMAS: We have done a large number
10 of things. In looking at both, trying to determine the
11 ignition source, and trying to determine what we can do
12 to find the ignition source, we have done a lot of work
13 in that area with the NTSB.

14 CHAIRMAN HALL: Do you all have an idea of
15 how many ignition sources there are in that center
16 tank?

17 WITNESS THOMAS: It's the gauging system and
18 the pumps. We know the pumps were not running.

19 CHAIRMAN HALL: Well, if I said there were 60
20 or 70, would that be fair? Can you put a number on it,
21 or could you come back to us with a number of how many
22 ignition sources we have?

23 WITNESS THOMAS: I would certainly try.

24 CHAIRMAN HALL: I would appreciate it.

25 I was very interested in what Boeing has done

1 because I know you have done quite a bit, and I would
2 like on the public record for the public to know what
3 Boeing has done.

4 DR. BIRKY: I'd like to, if I might, follow
5 up on the question that Dr. Loeb was asking.

6 CHAIRMAN HALL: I'm in the middle of
7 something here. I'm sorry.

8 DR. BIRKY: I'm sorry.

9 CHAIRMAN HALL: Please proceed, Mr. Thomas.

10 WITNESS THOMAS: We have in effect the
11 accident investigation support to the NTSB going on on
12 a regular on-going basis. We supported all the
13 activities in that regard in the hunt for the ignition
14 source. At the same time, we have started, in fact,
15 back as far as the Fall of last year, looking at the
16 flammability issue.

17 When it became obvious that we were not going
18 to find the ignition source very quickly in this
19 accident, I think we started, prompted, I think, in
20 part by your own letter of recommendation which
21 addressed flammability. We had spent a lot of time
22 building computer models to understand the issue around
23 flammability.

24 We looked at alternatives. We took the
25 opportunity when the NTSB was flying the Evergreen

1 airplane to fly additional flight tests on that
2 airplane, both to look at the effect of, could we do
3 some kind of pack bay cooling.

4 The issue here is how much heat is generated
5 by the air-conditioning packs underneath the fuel tank.
6 We ran flight tests to try and get some very
7 preliminary data that we could upgrade on computer
8 modeling of the situation. We have done extensive
9 modeling up to this point to look at those kinds of
10 things .

11 One of the suggestions, I think it was in the
12 docket, where the Press talked about its sweeping as an
13 alternative to this. We have run very simple
14 laboratory tests to see whether sweeping can be
15 utilized. So, we're taking a multiple approach to
16 this . We are progressing carefully.

17 We are concerned, as you said in your opening
18 remarks. Airplanes are remarkably safe. Our concern
19 is, we not rush into something unnecessarily, and we
20 want to make sure what we're doing is adding safety,
21 and we don't have some side effect that can cause a
22 worse condition.

23 And that is why we occasionally appear to be
24 slow, but we would much prefer to be slow and careful
25 and correct than rushing into something, and then we

1 find out six months later, it was the wrong thing to
2 do.

3 CHAIRMAN HALL: Well, I appreciate that, Mr.
4 Thomas, and let me say, I don't think that the Board
5 wants you all to rush into anything that's unsafe. We
6 do want you to rush into looking at the problem.

7 WITNESS THOMAS: That, we are doing, sir.

8 CHAIRMAN HALL: I appreciate that.

9 Dr. Birky, I'm sorry.

10 DR. BIRKY: My apologies, sir.

11 Yes. I had a question following up on the
12 Filipino accident. Were there changes made in the 737
13 center tank system as a result of that?

14 WITNESS THOMAS: No, we did not make any
15 changes. When we failed to find any specific cause for
16 that accident and we had exhaustively tested every
17 component that could be a potential ignition source, we
18 at that point concluded the investigation.

19 There was an issue over whether the boost
20 pumps were an ignition source, and whether they had
21 been running a long time on that airplane, as you are
22 familiar with the airplane.

23 We put out flight operations instructions to
24 the airlines to remind them that we should not be
25 running the pumps dry for a long time, even though we

1 qualified that the pumps would be able to run dry.
2 There is no reason to do so when the tank has no fuel
3 in it. And we put out those instructions.

4 DR. LOEB: I'd like to follow-up on that.
5 Another possible ignition source that was proffered at
6 the time, was the possibility of the floats, which
7 getting power into the floats which was beyond what the
8 system would have been designed for, perhaps through
9 the logo light wiring, did Boeing do anything regarding
10 the floats which were the running of wires that are
11 proximate to fuel tank wires that did carry larger
12 voltages?

13 WITNESS THOMAS: I'm not aware of the
14 specifics of the electrical system. I know we tested
15 and looked at the floats which is very carefully --

16 CHAIRMAN HALL: Well, Mr. Thomas, I would
17 appreciate it if you could, because if I understand as
18 a layman, you're saying that the philosophy is, you've
19 got to engineer out the ignition sources, and it would
20 seem to me, you need to know first then what are the
21 ignition sources in the tank, how many there are and
22 where they are, so you can be sure they are very
23 carefully taken care of, so if your philosophy is, this
24 tank is flammable all the time, I've got to know how
25 many possibilities I'm dealing with. Am I making sense

1 in this?

2 WITNESS THOMAS: You are making sense, sir,
3 and fundamentally, we have the sources of energy into
4 the tank are either the boost pumps themselves and
5 whether or not they can transmit energy into the tanks,
6 and we test those pumps, as I explained earlier.

7 The other source of energy is electrical
8 energy coming in on the gauging systems. We need to
9 look very carefully at the gauging system to see if
10 there are any problems with energy coming from the
11 airplane on the gauging system wires.

12 One of the reasons we test the gauging system
13 to 1,500 volts, is to make sure that a short or
14 something else that happens in the airplane cannot
15 cause a spark combined, introducing high voltages onto
16 the gauging system.

17 The float switch on the 737, as I understand
18 it, there was a question over whether or not the float
19 valve itself could get high enough; in other words,
20 would a short generate enough temperature to cause an
21 ignition. With the FAA's participation, we ran a lot
22 of tests on those float switches and could not
23 determine that there was any kind of temperature
24 problem with that.

25 CHAIRMAN HALL: But, I guess again, I go back

1 to the FAA, and if you accept this philosophy, and I
2 know that in the late Sixties, I was in the Military,
3 and I don't know whether you all were with FAA and
4 Boeing at the time, but I know this was done in the
5 late Sixties, but someone said, "We're going to certify
6 these aircraft. We're going to make the assumption
7 that the fuel tank is flammable, and we're going to
8 engineer out the ignition sources."

9 Does the FAA identify the ignition sources,
10 Mr. Cheney?

11 WITNESS CHENEY: Well, the end of the effort
12 would be that there are no ignition sources, and what
13 has to be evaluated is, what are the possible ignition
14 sources? And that would be the fuel quantity system
15 and the pumps and any adjacent heating.

16 At the conclusion of the evaluation, the
17 testing and analysis should be a finding that they
18 don't constitute ignition sources.

19 I would like to --

20 CHAIRMAN HALL: Is there a number that you
21 have on possible ignition sources that is developed at
22 all?

23 WITNESS CHENEY: It should be zero. There
24 aren't ignition sources. The problem we've got in the
25 situation like that --

1 CHAIRMAN HALL: Zero on ignition sources or
2 zero on possible ignition sources?

3 WITNESS CHENEY: Ignition sources that would
4 constitute temperature that would ignite the vapor
5 should be none.

6 CHAIRMAN HALL: So what happened with the
7 Philippines 737?

8 WITNESS CHENEY: No one has the answer to
9 that, and that's why --

10 CHAIRMAN HALL: And so, what if we end up now
11 with TWA-800 and none of us have an answer at the end
12 of this extensive investigation, which I am hoping will
13 not be the guess, but let's assume that is the case,
14 then what do we do?

15 WITNESS CHENEY: This is why we are seriously
16 embracing attacking this problem at the flammable vapor
17 level. We cannot say that ignition sources in cases
18 like Powell are gone. We don't know what they are. We
19 exhausted every component.

20 CHAIRMAN HALL: Thank you.

21 Mr. Swaim, you'd better get us back on track
22 here.

23 MR. SWAIM: Thank you, sir.

24 We do have a separate panel probably starting
25 this afternoon or tomorrow for ignition sources, and

1 I'm sure we will be exploring this much further.

2 CHAIRMAN HALL: That's fuel, too. Are we
3 going to discuss fuel?

4 MR. SWAIM: Yes, that's this afternoon, too.

5 From Mr. Hinderberger, we have an
6 illustration showing locations of air-conditioning
7 equipment called packs, and several other models of
8 airplanes and the examples we put up where the L-1011,
9 the DC-10, the DC-9, which is essentially the same as
10 the MB-80 and the other newer airplanes.

11 In the case of Douglas, why weren't the packs
12 located in that convenient under-the-wings center
13 section where Boeing and Air Bus have put their air-
14 conditioning equipment?

15 WITNESS HINDERBERGER: Well, Mr. Swaim, the
16 best way to answer that question is to describe that in
17 this manner: The most ideal location for the air-
18 conditioning packs is the nearest intersection of the
19 pneumatic systems on the airplane.

20 As you can see from the illustration for the
21 DC-9, and is also the same for the MB-80 and MB-90,
22 that nearest intersection is in the back of the
23 airplane between the engines.

24 On the DC-10 the nearest intersection of all
25 the pneumatic systems would indeed be in the center

1 wing tank area. What occurred on the DC-10 as the air-
2 conditioning packs were being designed is, the size of
3 the air-conditioning packs was larger than the
4 available space between the center wing tank and the
5 faring that runs between the wing and the fuselage.

6 Therefore, an alternate location for the air-
7 conditioning packs had to be found. That alternate
8 location was in the nose of the airplane, outboard of
9 the nose wheel well.

10 MR. SWAIM: Very good. Appreciate it. Go
11 ahead.

12 DR. LOEB: Bob, if I could just interrupt.
13 Was there any consideration given in the location of
14 the packs to the notion that it may be better not to
15 have heat sources adjacent to the fuel tank?

16 WITNESS HINDERBERGER: Well, Dr. Loeb, as it
17 pertains to the packs in the Douglas philosophy, we did
18 not have a philosophy which said that the air-
19 conditioning packs should be located away from the fuel
20 tanks. In fact, in our later design studies for
21 airplanes that we didn't proceed on, we had designs,
22 albeit preliminary, where our air-conditioning packs
23 were located underneath the center wing tank. Those
24 designs were, of course, on airplanes with larger wings
25 and a larger area between the center wing tank and the

1 faring.

2 so, we indeed had designs available to us,
3 and we're planning to execute those designs with the
4 packs under the center wing tank.

5 DR. LOEB: So there was no consideration
6 given to the notion that it may be safer not to have
7 the heat adjacent to the tanks, and it was just
8 fortuitous?

9 WITNESS HINDERBERGER: That's correct.

10 MR. SWAIM: Just for reference, the center
11 photo behind the witness panel is the forward end of a
12 Boeing 747 air-conditioning pack number 3, and
13 immediately to the right of the round object is the
14 bottom of the fuel tank. The photo to the right is the
15 inside of the fuel tank above that.

16 Mr. Rodriguez, how does the Military design
17 and certify fuel systems? You're buying from both of
18 these companies. Is it different? How do you certify
19 fuel systems?

20

21 BEATRIS RODRIGUEZ, USAF

22 Military Fuel Systems

23

24 MS . RODRIGUEZ: As part of the Air Force
25 aircraft fuel certification process, the Air Force

1 requires a verification and validation test plan for
2 functional and performance requirements. The
3 verification and validation test plan is developed
4 working with the contractor. We required extensive
5 analysis, inspection, demonstration during ground and
6 flight tests.

7 We required analysis on engine feed fuel
8 transfer, refuel, defuel, thermal, all the subsystems,
9 gauging in the aircraft has a gauging system.

10 In addition, we request system and component
11 failure analysis in addition to aircraft normal
12 operations .

13 The ground test represents the most intensive
14 verification process where we conduct ground tests.
15 Sometimes when we built simulators, we conduct
16 extensive tests on the simulator. We conduct bench
17 tests, and the component quality test is normally done
18 at the supplier.

19 so, factory tests, we do leak checks for the
20 plumbing. We take the plumbing to proof pressure
21 levels, the components do to verify their structural
22 integrity, and leak integrity. There shall be no leak.

23 We also bonding tests. The bonding tests are
24 performed to verify the electrical activity of the
25 plumbing and components and proper grounding structure.

1 We pressurize our tanks to verify for a leak.
2 We conduct dry and wet tests, punch all tests. All the
3 subsystems are tested. We do engine feed test to
4 normal flight altitude, landing. We do fuel
5 calibration, and the fuel calibration test, what we
6 verify is the fuel quantity integrity and the trap fuel
7 that we might have.

8 We ensure that any jettison fuel or any fuel
9 leaks will not be ingested in the engine, or will not
10 flow into any potential ignition sources of aircraft.

11 After we complete all this, that's at the
12 time the Air Force requests executive independent
13 review team where similar level of people review our
14 process, our certification process of the data,
15 qualification test, functional test, hazard analysis
16 for the system, and safety to fly clearances provided.

17 After safety to fly, of course, flight test
18 follows.

19 MR. SWAIM: Very good. So, in more English
20 terms, is it pretty much the same an airplane, or do
21 you not know, since you're an Air Force employee, or do
22 you want to defer that to the manufacturers?

23 MS . RODRIGUEZ: One thing I could mention is,
24 we are constantly buying derivatives from commercial
25 airplanes. We do buy FAA's certified aircraft, and we

1 make modification to those aircraft based on Air Force
2 mission. Most of the time in the fuel system area,
3 some of those modifications have to do with air
4 refueling mission that's a mission requirement for that
5 particular aircraft.

6 so, we run supplemental certification, but
7 overall, we use a lot of commercial practices,
8 especially these days that Air Force would put some
9 contract on our performance requirement.

10 MR. SWAIM: SO, if the military planes are
11 designed to accept a particular risk, say, air-to-air
12 refueling, since you're accepting a certain type of
13 risk that the civilian world would not have, would you
14 say your certification standards are any less
15 stringent, more stringent?

16 MS . RODRIGUEZ: For every fueling
17 certification, if it's an off-the-shelf aircraft with
18 fueling certification, we are probably just going to
19 look at that modification, particular modification, and
20 we will do analysis to verify that the vent system
21 could withstand any metal control failure in flight or
22 every fueling in-line separation.

23 We looked at tank bottom pressures during our
24 refueling. We looked at the pressures that you might
25 generate when you're doing the filling up of the tanks.

1 All that is done as part of analysis. You do a failure
2 mode analysis effect where you conduct ground tests
3 where you simulate a tanker on the ground, and you
4 conduct your functional check. There is a lot of
5 certification of this part of the structure for the
6 receptacle beams strike loads, their receptacle
7 installation, the drainage system.

8 so, you certify that every fueling system,
9 based on your mission, is not that it is more
10 stringent; it's just a procedure that you have to
11 follow through.

12 MR. SWAIM: Going back to the 74 and some of
13 the things that Mr. Thomas was talking about, Mr.
14 Taylor, you're from the manufacturer of the fuel
15 quantity system. Can you please show us the basics of
16 Honeywell and the basics of the fuel quantity
17 indication system, how it functions in the airplane?

18 WITNESS TAYLOR: Yes. I have a short
19 presentation that I could give at this point, if that
20 would work.

21 MR. SWAIM: Mr. Chairman?

22 CHAIRMAN HALL: I'm sorry.

23 MR. SWAIM: Mr. Taylor says he has a short
24 presentation, if that's acceptable?

25 CHAIRMAN HALL: I'd love to hear it.

1 MR. SWAIM: Okay.

2

3

LOU TAYLOR, Honeywell

4

Fuel Quantity Indication System

5

6

WITNESS TAYLOR: This is a short presentation
7 on how the Honeywell fuel quantity system works, and
8 it's intended to try and get across the message of what
9 this is.

10

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The fuel quantity indicating system is really
a fancy name for an airplane fuel gauge. It basically
does the same function as the fuel gauge on your car
does. So, if it's working with aviation fuels, except
gasoline on your car which measures fuel by the
gallons, this measures fuel in columns which is a more
appropriate way of looking at how a jet engine uses
fuel .

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Honeywell first got into the capacitance
measurement business in 1942. We developed an ice
detection sensor, and then later on, we started
building capacitive type fuel quantity measuring
systems, and the first was just for the Boeing B-29.

23

24

25

Since then, we built systems for most of the
major aircraft manufacturers in the U. S. We went to
the Boeing 377 Strata Cruiser, the Boeing 707 and 720,

1 the 747 Classic that we're doing with here; the 57 and
2 67. Douglas Aircraft included DC-6, DC-7 and DC-8.
3 There are various Military applications, and we also
4 have built liquid fuel measurement systems for various
5 spacecraft.

6 Honeywell Systems have prove to be very safe
7 and reliable throughout their history. The in-tank
8 equipment that we're dealing with, the tank and probes
9 - we use that term interchangeable - these were
10 designed to have a 2 million hour mean time between
11 failure.

12 With 65 probes in the aircraft in the case of
13 the 747 and the number of flight hours that were
14 mentioned yesterday, we're looking at in excess of 2
15 billion flight hours on tank units, and we don't have
16 any safety issues.

17 We will take a brief look at what the
18 products are, and get you familiar with them. I
19 brought some show and tell items with me.

20 On the flight engineer's panel, you have the
21 fuel quantity indicator, and this is one of the fuel
22 quantity indicators. This is an indicator from the
23 center tank. You have one indicator per-tank. Also on
24 the flight engineer's panel, you have a fuel totalizer.
25 This is one of the totalizers which shows the total

1 field quantity, and it also shows the total aircraft
2 gross weight.

3 In the fuel tank, you have the tank units or
4 tank probes. There are 65 on the aircraft. There are
5 7 in the center tank, and Ivor had a diagram which
6 showed where they are. This is one of the tank units
7 from the center tank. They're fairly long. They run
8 from almost to the floor to almost to the ceiling.
9 Tank units throughout the aircraft are various sizes,
10 various configurations to fit the need of the various
11 point of use.

12 Also in the tank, we have a compensator.
13 This is one of the compensators. Now, the purpose of a
14 compensator is to adjust to the different
15 characteristics of fuel, since Jet A or the various
16 types of fuel, what we use in JP-4 and 8, or just the
17 variations within a given type of fuel, it changes.
18 so, this will compensate for those differences in the
19 fuel characteristics.

20 Out on the refueling panel on the left wing,
21 you have another set of indicators just like the ones
22 that are up on the flight engineer's panel. The
23 purpose there is for the refueling crew to be able to
24 see how much fuel is in each tank, and shut off
25 refueling at the appropriate level so they put the

1 correct load on the aircraft.

2 One other item in the electrical equipment
3 bay down below the pilots, there's a volumetric shut
4 off computer, this thing (indicating) . The purpose of
5 this device is to automatically shut off fueling when
6 the tank is full. It's to prevent overfuel in the
7 aircraft, so this is a stop gap automatic shut off.

8 One of the things I'd like to clarify at this
9 point, the fuel flow was mentioned yesterday, and fuel
10 flow is not a part of this system. Any issues with
11 fuel flow are not dealt with here.

12 MR. SWAIM: Excuse me. Does the volumetric
13 box, the computer you have your hand on, is that taking
14 in the signal from the fuel probes in the tank or the
15 compensator?

16 WITNESS TAYLOR: This takes a signal from the
17 fuel quantity indicator, and it also has compensators
18 of its own in the tank, in four other tanks.

19 MR. SWAIM: Thank you.

20 WITNESS TAYLOR: I mentioned this is a
21 capacitive type system. I will give you a description
22 of what a capacitive type system is. The indicator is
23 what's known as a rebalance ridge type indicator. The
24 tank units - we have a shorter one here that's a little
25 easier to talk to, and each section is open so you can

1 see the inside - we operate these at a fixed voltage,
2 and the capacitance of the tank changes. So, we're
3 using this as a variable capacitor.

4 The compensator is designed to be in the
5 bottom of the tank. It will be submerged in fuel all
6 the time until you have the last couple of inches of
7 fuel in the tank, and this acts as a fixed capacitor,
8 and we vary the voltage to that.

9 The next slide we have up here, it's a
10 conceptual view of what a rebalance system is and how
11 this works. It is shown at the top, and this is shown
12 as a variable capacitor. The compensator down below
13 that is shown as a fixed capacitor. We input a fixed
14 voltage into the tank, and that's shown as this E
15 fixed, and that creates a very small current, it's I
16 sub S, which is our sensed current.

17 Also, from the compensator, you have I sub b,
18 which is the balanced current, and if these two are in
19 balance with each other, then whatever comes out of one
20 goes into the other, and vice versa. I think it would
21 be kind of like a slinky. If you put a slinky in your
22 hand and run it back and forth, it goes from one hand
23 to the other, and that's it. Nothing goes anywhere
24 else.

25 If they're slightly out of balance, we create

1 a rebalance signal, and it's a very, very small signal.
2 We run that through an amplifier, and the amplifier
3 runs a small motor inside the indicator, and we take a
4 look at that, and that motor will change the indication
5 on the face, so you move the dial. It also moves the
6 variable resistor. It's a ten turn precision for the
7 potentiometer, and that adjusts the voltage going back
8 to the compensator. So, it's really a very simple
9 basic system. It balances against each other if there
10 is any slight imbalance. It automatically adjusts and
11 mechanically does both the potentiometer and the
12 indicator at the same time.

13 The next one gives you a little different
14 view of some of the same information. Going from the
15 sensor you have in a tank, which would be the tank in
16 it, that would be connected to the bridge circuit
17 inside the indicator. If that bridge has any out of
18 balance that goes over to the amplifier, the amplifier
19 runs the motor, and then the motor is connected. There
20 is a gear train in here both to the indicator face and
21 to the feedback potentiometer.

22 This is a very common factor used in a lot of
23 this type of equipment.

24 The totalizer we mentioned, is also up in the
25 flight engine of your panel. It's connected to each

1 one of the indicators, and it will take the fuel
2 indication from each of the indicators and add it up.
3 In this case, it's showing 298,000 pounds of the total
4 fuel. At the beginning of the flight, the flight
5 engineer can set the gross weight of the aircraft for
6 this particular flight. In this case, it says 648,000
7 pounds.

8 During the course of the flight, as fuel is
9 used, that will indicate both on the total fuel, and
10 total fuel on board will decrease, and of course,
11 finally, the gross weight will decrease. So, at any
12 point in time, the flight engineer has one gauge he can
13 look at and say, "Here is my total fuel," and also,
14 "Here is my total gross weight."

15 The tank in it is really just two concentric
16 metal cylinders, one inside the other. The outer
17 cylinder is an anti-die aluminum, and it has an inside
18 diameter of 1.8 inches. All of the tank units have the
19 same diameter straight tube outer element. We have
20 varying lengths, depending on where they go in the
21 tank.

22 The inner element is electrolysis nickel, and
23 you can see on the diagram here that it changes
24 diameters. If the fuel tank was just a pure square
25 rectangular box, this would be a straight tube. But

1 the fuel tank is not regular shaped. There are various
2 other pieces in there, and as you go up vertically in
3 height, what we're doing is, changing the diameter of
4 the inner element, and that means that the capacitance
5 will change directly with change in fuel quantity.

6 Mounting these on a tank, typical mounting
7 would be on some structure member in the tank. You 'd
8 have a tank in it mounted with the bottom fairly close
9 to the floor, not sitting on it, but slight above the
10 floor, and it would be sensing whatever the fuel level
11 is.

12 The compensator, one per-tank, would be
13 mounted at the low point in the tank, and, as I said,
14 would be submerged in the fuel until you get down to
15 the last couple of inches of fuel.

16 MR. SWAIM: So these would be the wires that
17 Mr. Cheney was referring to, running inside the fuel
18 tank?

19 WITNESS TAYLOR: Yes. This is the in-tank
20 wiring coming from the tank wall connector box, and
21 would run to the various tank compensators.

22 The volumetric shut off, as I said, takes the
23 indication from each of the fuel quantity indicators.
24 The fuel quantity indicators is telling you the mass of
25 fuel, the number of pounds of fuel you've got on board,

1 and the engine creates energy based on the mass of
2 fuel .

3 But to deal with the volumetric shut off, you
4 want to know what's the volume you have so you don't
5 over-fuel the tank. So, the indicator will tell the
6 volumetric shut off what the mass of fuel is, and then
7 there are separate compensators that the volumetric
8 shut off uses, same part number; just an extra one in a
9 couple of the tanks. And that allows the volumetric
10 shut off to back out into a volume and say, here is the
11 volume on the front of the box. There's a little
12 plate, and underneath that are adjustment parts.

13 When it's installed in the aircraft, the
14 maintenance people will adjust this so that it will
15 automatically shut off when that particular tank
16 reaches its full volume.

17 If you take a brief look at some of our
18 product testing, product testing really falls into two
19 areas: One of them is qualification testing. The
20 system was designed to meet the Boeing requirements.
21 Part of those Boeing requirements were rather extensive
22 qualifications . In it was tested to those
23 qualifications, and the reports were given to Boeing,
24 and that was the original design level.

25 The second level of testing is production

1 testing. Everything that goes in the tank - and I'm
2 focusing here particularly on tanking because that's
3 the in tank hardware - it runs through three tests.
4 There is a resistance test where, when you connect to
5 the terminal block, would check all possible
6 combinations and connections, and we're looking for a
7 minimum resistance of 500 mega ohms. Basically, we're
8 saying there is no short, there is no connection
9 anywhere in it.

10 The second check is a capacitance test, and
11 that's really an accuracy test. It says this
12 particular probe is supposed to give you a certain
13 capacitance, and does it do that? Is it going to give
14 you the right fuel quantity measurement?

15 And the third test is called the high pot, or
16 high potential test. We will put 1,500 volts and cross
17 all possible connections, and the unit has to withstand
18 1,500 volts without breaking down. The limit we have
19 for that is a maximum of one-half of a milliamp of
20 current at 1,500 volts. If it fails that, it's failed
21 its production test and it goes back.

22 I wanted to talk a little bit about the
23 system safeguards. One of the prime safeguards is
24 current limiting. We're talking about the current in
25 the system. The indicator --

1 CHAIRMAN HALL: Could I just ask one
2 question, Mr. Taylor: How many possible ignition
3 sources are there in the system you're describing to
4 us?

5 WITNESS TAYLOR: I believe the answer is
6 none. What we're putting into this is an energy that
7 is extremely low, and is well below any ignition level.
8 There is wiring that comes to the tank units.

9 DR. LOEB: Excuse me. Could I just ask a
10 clarifying question to that to follow-up the question
11 that Sherman asked. You were saying, if there is no
12 other failure, if there is no failure in the system,
13 then you would have no ignition sources with this
14 system; is that correct?

15 WITNESS TAYLOR: That's correct.

16 DR. LOEB: If there are failures of a variety
17 of metals floating around, or shorts from wiring
18 outside, with wiring inside, and so forth, then, is
19 there the possibility of potential ignition sources?

20 WITNESS TAYLOR: I'd say we have not seen any
21 indication of it.

22 DR. LOEB: Is there the potential of possible
23 ignition sources?

24 WITNESS TAYLOR: I don't know the answer to
25 that.

1 DR. LOEB: Okay. Thank you.

2 WITNESS TAYLOR: That's what a lot of people
3 are looking for, and we don't have it yet.

4 DR. LOEB: Thank you.

5 WITNESS TAYLOR: The wiring you mentioned
6 does connect to the terminal block, so you do have in
7 tank wiring that connects. We try and test this so
8 that we put in very, very extreme conditions with a
9 1,500 volt test and make sure that it's not going to
10 break down there.

11 CHAIRMAN HALL: What type of wiring do you
12 use?

13 WITNESS TAYLOR: The wiring is provided by
14 Boeing. We don't provide the wiring.

15 CHAIRMAN HALL: So how do you do your tests
16 then?

17 WITNESS TAYLOR: We're testing the tank unit
18 itself. We will connect a --

19 CHAIRMAN HALL: But if you use a test, don't
20 you use some kind of wiring for the test?

21 WITNESS TAYLOR: Yeah, the wiring we will use
22 for our test set-up.

23 CHAIRMAN HALL: Yes. What type of wiring is
24 that?

25 WITNESS TAYLOR: I know that the in tank

1 wiring is a teflon coated copper strand silver coated
2 wire . I don't know if we need to use that same quality
3 on our tester or not. We certainly could, and we
4 probably do.

5 MR. SWAIM: Maybe that question will be more
6 appropriate to Mr. Hulm, who is the electrical design
7 Manager for Boeing.

8 WITNESS TAYLOR: The wiring in the tank and
9 in the airplane is tested to the same levels that the
10 tank units are, and are tested independently by the
11 manufacturer of those harnesses, either Boeing in some
12 cases, or our supplier for some of the in tank
13 harnesses.

14 CHAIRMAN HALL: I guess my point, Mr. Hulm, I
15 guess in reading all the exhibits and material, the
16 wiring has changed, the type of wiring since the
17 Sixties to the present, has it not? And I'm patient
18 for listening to presentations, but I want to know how
19 they also apply to what we're talking about today, and
20 whether this information is the tests that are being
21 described, also, that the safety systems are the things
22 that apply to the 1960s we were referring to earlier.

23 MR. HULM: Yes. The test conditions that
24 we're looking at here with the 1,500 volt AC test and
25 the inflation resistance test, those are basically

1 still the same things we use today. The wiring has
2 changed and the technology has changed. Some
3 improvements have been made in the wiring itself as far
4 as the characteristics as the installation, its weight
5 and cost, and things like that.

6 But the basic test methodology has remained
7 the same. So, the integrity is still there, regardless
8 of what generation that the equivalent is produced in

9 CHAIRMAN HALL: So, the test you're ascribing
10 to us, Mr. Taylor, are these current tests, or these
11 tests that you had in the 1960s on this equipment?

12 WITNESS TAYLOR: What I'm describing now is
13 the production level tests are current tests.
14 Everything we build gets this test when it's
15 manufactured. Also, when we repair a unit, if we
16 repair at Honeywell, we do the same level of testing.

17 CHAIRMAN HALL: And this was the same as in
18 the 1960s? I understand some of this equipment is
19 original equipment, right, in the flight?

20 WITNESS TAYLOR: It's very likely that this
21 is the original equipment with a 2 million hour MTBF.
22 We very commonly see probes go on an aircraft, and it
23 will be there through its entire operating life.

24 CHAIRMAN HALL: So, were these tests the same
25 tests in the 1960s? This is my only question.

1 WITNESS TAYLOR: Those are the same tests.

2 CHAIRMAN HALL: So the presentation you are
3 giving to us is applicable. It would have been the
4 same presentation we would have gotten in '68, '69?

5 WITNESS TAYLOR: Twenty-five years ago, it
6 would be the same information.

7 We were talking about the current limits.
8 The indicator provides power to the units in the tank.
9 The wiring comes from the tank up to the flight
10 engineer's panel, and that's the only connection it
11 goes to.

12 Normal operations, the indicator works, or
13 the system works at less than a million amps. It works
14 about 300 microamps, or a third of an amp. In the
15 indicator, we have current limiting circuitry, and
16 normally, this is sealed, but we sliced this one open
17 so we can get to it. We can put this up on the MO. We
18 can get that up and we will show you some of the
19 circuitry.

20 The normal operations is for the 10 milliamp.
21 I was hoping to get these on the overhead because these
22 are really small components. But we have these tiny
23 components which are a part of our current limiting.
24 Those provide 10 milliamp protection. If they fail,
25 their normal condition would be to fail to open and

1 just shut the thing down.

2 In the unlikely event that they should fail
3 short, then there is 150 milliamp limit, and that's
4 just a natural resistance of a device. It's the most
5 you can get through this.

6 Also, along with this, the system is designed
7 to meet the requirement that Boeing has. The maximum
8 amount of energy that we can deliver to the tank is .02
9 millijewels, or it's the 20 microjewel level.

10 We were trying to find a way to put this in
11 perspective. We're talking about a lot of numbers,
12 milliamps and millijewels and trying to figure out what
13 that really is. And we started out with a flashlight,
14 you know, just a regular two double A battery
15 flashlight, and what kind of current does that draw?
16 Would that give us a reference?

17 Well, that draws about 800 milliamps, far in
18 excess of what we're doing here. We went from there to
19 one of the little minimag flashlights, and that still
20 draws 320 milliamps, not really a good reference.

21 What we wound up with, so we took my pager,
22 and my pager sitting here right now in its normal
23 passive system, it draws about 1-1/2 milliamps, or it
24 draws five times the current that the fuel quantity
25 system draws in a normal operation. When my pager goes

1 off, it draws about 45 milliamps, or between four and
2 five times our current limit.

3 One of the things we did with the indicator
4 from the accident aircraft, that was recovered, and one
5 of the events was to reconstruct that indicator. We
6 did need to replace some components to make it
7 functional. When we replaced these components, it was
8 functional. We did an independent failure analysis on
9 all of the components that were replaced, and
10 everything we had to replace was either damaged by
11 impact, or by exposure to salt water, and the
12 conclusion we had from that was that the indicator was
13 functional for the center wing tank at the time of the
14 accident. So, all of the current limiting circuitry
15 was functional.

16 Voltage is the other thing we were going to
17 talk about, and we talked about testing this to 1,500
18 volts. The normal operating voltage for tank units, in
19 the center wing tank, we operate these at 5 volts. The
20 compensator, which is described as a variable voltage,
21 in the near-empty tank condition that we have here, we
22 are near zero voltage.

23 MR. SWAIM: But what can that get up to?

24 WITNESS TAYLOR: At a full tank, they run to
25 approximately 25 volts. One of the things we did also

1 to try and put this in perspective, you can hang onto
2 the wiring and you don't feel a thing. You have no
3 idea if this is on or off if you're holding the wires.
4 so, this is an extremely low energy system.

5 That concludes my presentation. I hope it's
6 given you some understanding of the system we're
7 working with.

8 Thank you.

9 CHAIRMAN HALL: We're just about where we
10 need to take a break here. We have been going for
11 about an hour and 50 minutes, and this is probably a
12 good time to take a 15-minute break, and we will start
13 promptly again five minutes after the hour.

14 (Whereupon, a brief recess was taken.)

15 CHAIRMAN HALL: We will reconvene this
16 hearing of the National Transportation Safety Board.
17 We're in the middle of the discussion of agenda item 5,
18 Fuel Tank Design Philosophy and Certification, and we
19 have heard from our Technical Panel and from the panel
20 that has expert witnesses in place.

21 Mr. Swaim, would you please continue with the
22 questioning.

23 MR. SWAIM: Certainly, but I know Dr. Birky
24 has a question he'd like to interject here.

25 DR. BIRKY: I'd like to ask a question on Mr.

1 Taylor's presentation.

2 Do you do any follow-up testing on these
3 probes to see how well they are meeting the initial
4 test requirements?

5 WITNESS TAYLOR: I think the answer to that
6 is, we do many repairs or recertification to a probe.
7 They would receive that same testing level that I
8 talked about, the 500 mega ohm resistance capacitance
9 and the 1,500 volt high pot test.

10 DR. BIRKY: So, after a probe has been in
11 service for a number of years, you would re-evaluate it
12 and see if it's still meeting the criteria?

13 WITNESS TAYLOR: If it's returned to
14 Honeywell for any maintenance or repair action. We
15 also had some probes that were evaluated, and some
16 testing that was done in conjunction with this, and the
17 in-coming test for that said that they met all their
18 requirements .

19 DR. BIRKY: Does Boeing have any follow-up
20 requirements to see if they are tested periodically and
21 still meet the design criteria?

22 MR. SWAIM: Is that a regular program, in
23 addition to his question?

24 MR. HULM: Boeing doesn't have a regular
25 program for monitoring the condition of the probes.

1 I'll tell you what we did do, though, as part of the
2 accident investigation is, we did pull some old probes,
3 23-year old probes off an airplane, along with its
4 wiring, and we tested that in our laboratory, and that
5 tested up to 3,300 volts AC, well past the 1,500 volt
6 AC dielectric test that the equipment was originally
7 qualified to.

8 so, the integrity on those components was
9 maintained for at least 23 years, and we haven't had
10 any evidence of the components we've seen or tested as
11 part of the investigation that that installation
12 resistance or the dielectrically standing test has been
13 compromised.

14 CHAIRMAN HALL: How long would those probes
15 last?

16 WITNESS TAYLOR: There is no design life
17 limits to the probes. They are intended to last for as
18 long as you want to keep the airplane in service.

19 CHAIRMAN HALL: So, it's on-condition failure
20 then?

21 WITNESS TAYLOR: It's on-condition only, and
22 that's it.

23 MR. SWAIM: Mr. Taylor, are those probes in
24 that system, since you make systems for the different
25 manufacturers, are those systems given by the

1 manufacturers as requirements? I know prior to the
2 747, you were building fiberglass fuel probes; or do
3 those truly come from Honeywell, the requirements for
4 how we're going to design a fuel probe system?

5 WITNESS TAYLOR: The requirement for the fuel
6 probe system for 747 came from Boeing.

7 MR. SWAIM: Okay.

8 WITNESS TAYLOR: As I said previously, we had
9 designed probes with the inner element made out of
10 fiberglass, and we built this probe to Boeing's
11 requirements .

12 CHAIRMAN HALL: Ms. Rodriguez, is there any
13 life in the Military, or any testing on this line of
14 questioning we're on now that's different from what's
15 in the commercial practice?

16 MS . RODRIGUEZ: Not that I am aware of. We
17 have a tech order that requires testing of all the
18 functionality of the fuel system, and the fuel probe
19 quantity gauging system is tested. And if it does not
20 test out, it has to be replaced, according to the tech
21 order data.

22 CHAIRMAN HALL: How often is that testing
23 done?

24 MS . RODRIGUEZ: It depends on the specific
25 aircraft. I will have to go to that particular tech

1 order and tell you exactly. I don't have a specific
2 kind.

3 MR. SWEEDLER: Mr. Cheney, are there any FAA
4 requirements for testing these probes once they are
5 placed in service?

6 WITNESS CHENEY: I think I would like my FAA
7 companion, Chris, to answer that. It's an electrical
8 issue that I don't have the background for.

9 WITNESS HARTONAS: The FAA does not have any
10 requirements for test probes in service.

11 MR. SWEEDLER: How about inspecting them?

12 WITNESS HARTONAS: As a result of the recent
13 investigations, the FAA may consider inspections for
14 probes . The FAA is extremely cautious about tanks and
15 disturbing of existing systems. So, it's a well
16 thought of process.

17 MR. SWEEDLER: How about inspection or
18 testing of other components, like pumps that we talked
19 about earlier?

20 WITNESS HARTONAS: The same applies.

21 CHAIRMAN HALL: Have there been an service
22 directives, service bulletins, or airworthiness
23 directives on any of this Honeywell equipment you
24 described to us, Mr. Taylor?

25 WITNESS TAYLOR: There have been no

1 airworthiness directives. Throughout the life of the
2 product, we have had five service bulletins on the
3 system.

4 CHAIRMAN HALL: Could you briefly describe
5 those for us?

6 WITNESS TAYLOR: Yes, I can, to the best of
7 my recollection. Three of them involve modifications.
8 There was a modification to the volumetric shut off.
9 Certain of the compensators were not being used any
10 more, so the components associated with that were
11 deleted.

12 There was a modification of one type of gauge
13 to another type of gauge. That was one of the service
14 bulletins. There is another mod in there. I don't
15 recall exactly what it is. One of the service
16 bulletins involved putting a solid cap on the top of
17 the terminal element. It's vented on the side, but
18 this would prevent condensation that may form on the
19 top of the tank and dripping down into the tank unit.

20 And the fifth one involves just moving the
21 name plate to a different location. So, it's almost 30
22 years of service, and those are the five service
23 bulletins we have.

24 CHAIRMAN HALL: Well, now, of all those, the
25 only one I understand is, why did they move the name

1 plate?

2 WITNESS TAYLOR: The reason for moving the
3 name plate was on a very, very short tank unit, and it
4 was actually in the middle. It was in a position where
5 it could give us some inaccurate indications. It was
6 really a functional indication problem.

7 CHAIRMAN HALL: Electrical problem?

8 WITNESS TAYLOR: It could possibly provide a
9 path between the inner and the outer electrode, and
10 then the indication would go away.

11 MR. SWAIM: Mr. Taylor, has Honeywell
12 designed capacitive probes installations to keep the
13 wire and the connections outside of the tank, just the
14 probes in the tank?

15 WITNESS TAYLOR: We have designed some tank
16 unit installations for the aircraft that are flange-
17 mounted, and the wiring would be outside. There is a
18 small amount of wiring that would through the flange
19 into the probe itself, an internal for the probe.

20 But there are flange-mounted systems where
21 most of the wiring is outside the tank, and we have
22 those both top flange and bottom flange.

23 MR. SWAIM: Okay. Thank you.

24 This is a photograph. It's a little burned
25 out . The photo in the lower left, the illustration,

1 these are wires that would be going between the cockpit
2 and the computer that you're showing that you had up on
3 the table, and the pointed in the very center of the
4 photo is to a wiring bundle that would carry the signal
5 to that computer.

6 So, my question to you, Mr. Taylor, are there
7 any protections in this system from Honeywell that you
8 know of that would protect against short circuits that
9 develop in airplane wiring? By the way, for a scale -
10 I'm sorry, one other thing - for a scale, at the right
11 end of that wiring bundle, it's pretty much in the
12 center of the photo, there are two fingers sticking
13 through a hole, and somebody is on the other side of
14 that panel, but at least that will give you an idea of
15 scale and where that bundle goes off to the left, it's
16 a little over three inches in diameter.

17 Mr. Taylor, I'm sorry.

18 WITNESS TAYLOR: In terms of protection, let
19 me address that in two areas. One of them, as I said,
20 the indicator has the wiring that connects to the tank
21 unit. Any problem with wiring would come to the
22 indicator, the supply wiring; the indicator would act
23 as a dam and would have current limiting, and would
24 only allow for the limited amounts of current through.

25 In the event that you have a short downstream

1 of the indicator, the level of protection it would have
2 would be the air gap between the inner and outer
3 electrode in the tank unit, and you'd have to have some
4 1,500 volts minimum that would test the tube to jump
5 that gap, as was mentioned in the testing that was
6 done, to find a breakdown level, it was 3,300 volts at
7 sea level. So, the air gap is really our protection.

8 MR. SWAIM: The air gap?

9 WITNESS TAYLOR: Downstream.

10 MR. SWAIM: Okay. And I know tomorrow, we
11 will have our ignition source panel who will be talking
12 about materials, including metal materials found in the
13 fuel tanks.

14 Mr. Hulm, I know there is a 50-pound pull
15 requirement for the fuel quantity wiring to attach to
16 the probe from Honeywell and the compensator. Can you
17 describe why, or what this 50-pound pull requirement
18 is? It's kind of a detailed question, but it's an odd
19 requirement, and I'm wondering if you have any
20 background on that.

21 MR. HULM: I don't know the direct answer to
22 that question. We have looked at it, and since a spec
23 was written, and we have not been able to figure out
24 exactly -- there are two possible reasons why that was
25 in there. One was if somebody did actually grab that

1 wire and pull on it, that the wire at the 50-pound
2 limit would break and prevent damage then to the
3 terminals themselves, or it was just to demonstrate that
4 if you did pull on it, it would stand up to 50 pounds
5 without damaging the probe.

6 so, we need to probably do a little more
7 investigative work there to figure out exactly why that
8 requirement is in there.

9 MR. SWAIM: Very good. I appreciate it.

10 Mr. Taylor, since you're not scheduled to be
11 on the ignition panel, I'd like to jump ahead a little
12 bit and ask you, if there has ever been any fuel tank
13 ignitions through the fuel quantity indication system
14 of any airplane that you know of?

15 WITNESS TAYLOR: No, none that we're aware
16 of.

17 MR. SWAIM: None that you're aware of?

18 WITNESS TAYLOR: None that we're aware of.

19 MR. SWAIM: Okay. Thank you.

20 There have been a couple of comments. Ms.
21 Rodriguez, I believe, mentioned the failure modes in
22 effects analysis.

23 Mr. Thomas, was there a failure modes in the
24 effects analysis or a fault tree requirement back in
25 about 1970?

1 WITNESS THOMAS: Not in that terminology. In
2 those days, the approach was to describe to the FAA the
3 system and the redundant speeches built into the
4 system, the testing that we did on all the components,
5 and the validations that we would do on the system,
6 both in ground test and flight test.

7 SO, in effect, we were building a fault tree
8 analysis by describing the system in great detail. We
9 have produced both an analysis document and a ground
10 testing and flight test document, all of which would be
11 submitted to the FAA for review and approval.

12 MR. SWAIM: Mr. Cheney, from your bio, I see
13 you have been working in the industry and with the FAA
14 for a few years. Would the fault tree or failure
15 analysis have been reviewed by the FAA, or would that
16 have been reviewed by Boeing's DERs for the FAA if that
17 would have been developed?

18 WITNESS CHENEY: The analysis that I'm aware
19 that was conducted was a safety analysis. That is
20 what was identified, and it was a qualitative analysis
21 that predicated the findings on the method by which the
22 qualification tests were run.

23 At that time, I don't believe it was a
24 requirement for a fault tree.

25 DR. LOEB: Excuse me, Bob. Is it possible,

1 Mr. Hulm, that you could explain what Boeing did to
2 address the issue of the potential for ignition sources
3 and engineering out the ignition sources, what they did
4 at the time that this tank was done, and what you would
5 do today, and maybe that would put this whole thing in
6 perspective?

7 MR. HULM: I think more in relation to what
8 we do today, the way we build or design these systems
9 is that, we look at each component individually, and
10 then we put it together in a system. As we look at
11 each component individually, if you take the Honeywell
12 indicator itself, they will go through a detailed
13 analysis that will examine each and every part of there
14 in terms of where its failure mode is and in terms of
15 what the effect of that failure mode is on the system
16 itself. And they will do that for the probes and for
17 the densitometers and for shut off units.

18 And then we at Boeing will take that system
19 as it's put into the airplane; we will examine then
20 what additional failure modes could occur to it, and as
21 far as the wiring itself and what it's exposed to, or
22 any of the indicators with the power we do supply to
23 those systems. We build quite a detailed analysis of
24 all of these different failures, and we determine which
25 ones we can detect and eliminate, which ones we can't.

1 If we can't stand, the failure mode of the ones we
2 can't detect, then we redesign the system so that we
3 can detect those particular failures.

4 I think the process used for the classic
5 airplane is pretty much the way Mr. Ivor Thomas
6 described it.

7 DR. LOEB: To what degree do you go back and
8 consider multiple failures, in other words, the
9 possibility of latent failures existing, and then
10 ending up with two or three different failures that can
11 result in the possibility of energy; to what extent, or
12 how far back do you go, or can you maybe explain a
13 little bit further?

14 MR. HULM: What we do in the case of multiple
15 failure is what I was alluding to. The fact that if we
16 come up against the situation where we do have a latent
17 failure that will go undetected, and we can't stand the
18 next failure, then we will redesign the system in order
19 to eliminate that failure.

20 There are other instances, though, where you
21 can imagine a lot of things as far as failing in the
22 system, and we try to evaluate to make our best
23 engineering judgment on what we think are likely
24 failures, and what are not so likely; and we look at
25 combinations of these failures, and as far as what we

1 think could or could not happen on an airplane, and try
2 to bring it back into reality.

3 so, we do look at multiple failures or
4 analyzing these systems, and we do take into account
5 those failures that would compromise the safety of the
6 aircraft.

7 DR. LOEB: For example, did you consider the
8 potential for shorts of ship wiring with the fuel
9 quantity indicating system and determining what may
10 happen under those conditions, or the possibility, and
11 we will be going into a number of these things with the
12 ignition panel, but the possibility, for example, of
13 metal contamination, metal getting into the probe
14 system and reducing the air gap or illuminating it.

15 How do you go about determining all of the
16 potential sources like that and then addressing them?
17 What's the mechanism for doing that?

18 MR. HULM: The failure modes, or each
19 individual instance that occurred, is really based on
20 the design and what the environment of the equipment
21 was installed in. So, in the case of a fuel tank, when
22 we look at that, we determine what the equipment is
23 subjected to, and what kind of failures we have seen
24 from service history, from previous designs we
25 experienced on other airplanes, and we look at that in

1 relation to how the current system that is being
2 designed.

3 In relation to the classic airplane, I don't
4 have the exact fault tree or methodology. They used to
5 do that. I know that is part of the accident
6 investigation. We did a detailed analysis like that,
7 and we took into account many of these factors
8 associated with damaged wiring and floating debris in
9 tank, and shorting of high voltage wiring onto the FQS
10 wiring.

11 Under those analysis conditions, we were not
12 able to determine a likely cause for the accident, so
13 those were taking into account.

14 MR. SWAIM: But the question there, Jerry,
15 Honeywell reported having no record of a structural
16 failure of a fuel probe. We went and asked them about
17 that. We asked them because there was a number in your
18 fault tree saying it would possibly break on this
19 schedule, tend to whatever exponent.

20 So, my question is: Where does Boeing come
21 up with some of these numbers? How are the failure
22 rates established?

23 MR. HULM: Well, you know, in the particular
24 instance of the structural damage, we have to make a
25 little bit of a judgment when we're looking at the data

1 returned from the airlines and what is returned to
2 Honeywell as far as what they are repairing, and
3 something called structural damage itself may be a
4 simple dent in the probe that results in a minor fuel
5 quantity indication. It doesn't necessarily mean that
6 the probe was destroyed or that it fell off or broke or
7 anything; it just means that it was removed from the
8 airplane due to some sort of external damage to it.

9 DR. LOEB: let me just follow-up a bit more.
10 so, the failure modes are in large part, or at least in
11 some strong part, dependent upon service experience, in
12 service experience, history, things that you've seen
13 and learned from the past; is that correct?

14 MR. HULM: Some of it, but, I mean, a lot of
15 it, you know, what we already know about the present
16 when we're looking at these systems, and the way you
17 design the electronics, or the mechanical construction
18 itself. It's tested for, you know, different
19 environments and under different stresses.

20 so, the current design knowledge, we have
21 that, especially for design in the new system, and we
22 take what we learned from the past and put that in
23 there, also. So, it's kind of a combination. It's not
24 just what we've seen in the past.

25 DR. LOEB: The problem is that we are

1 constantly learning about new things that's like new
2 things, and so it's difficult to predict what may
3 happen in the future, based solely on current
4 experience or the past; isn't that true?

5 MR. HULM: That's correct. You know, we're
6 constantly working with the airlines and the
7 manufacturer so if one of these instances do come up,
8 something we didn't take into consideration, that we do
9 correct i.

10 CHAIRMAN HALL: Mr. Hulm, do you have a
11 fault tree for the tank itself?

12 MR. HULM: For the --

13 CHAIRMAN HALL: Failure of the tank?

14 MR. HULM: The structural part?

15 CHAIRMAN HALL: Yes.

16 MR. HULM: Probably Mr. Thomas would better
17 answer that than I would be.

18 WITNESS THOMAS: I think the short answer is,
19 no, I don't think the structure is designed for the
20 life of the airplane. We shall get into in the aging
21 aircraft discussion later on this week. Basically, we
22 have a process of keeping that structure repaired
23 through inspection processes and repairs, and we assume
24 the structure will last the life of the airplane.

25 SO, there is no failure mode per se.

1 CHAIRMAN HALL: I was just wondering, because
2 the gentleman from Honeywell has made a presentation, I
3 guess it was on the scavenge pump, and you said it was
4 explosion-proof, a part of that component?

5 WITNESS TAYLOR: No. The scavenge pump is
6 not ours.

7 CHAIRMAN HALL: Well, what was the thing you
8 were referring to, Mr. Taylor, that you had the **diagram**
9 up there on?

10 WITNESS TAYLOR: I didn't mention "explosion-
11 proof."

12 WITNESS THOMAS: That was the boost pumps I
13 was talking about.

14 CHAIRMAN HALL: The boost pumps are
15 explosion-proof?

16 WITNESS THOMAS: Right .

17 CHAIRMAN HALL: so, I guess the average
18 citizen would say, "Well, why can't the tank be
19 explosion-proof?" I know there is a good answer, but
20 what is it?

21 WITNESS THOMAS: Are you talking to the
22 pressure of the tank?

23 CHAIRMAN HALL: Yes .

24 WITNESS THOMAS: Oh. Excuse me.

25 CHAIRMAN HALL: And you look at the failure.

1 The tanks have failed, I assume, and Military and
2 civilian experience you've had explosions; correct?

3 WITNESS THOMAS: Correct. We had this one.

4 CHAIRMAN HALL: Well, the 747 with the
5 Iranian Aire, the Philippines 737. Ms. Rodriguez and
6 Roy Pattman did a study in 1990 looking at a number of
7 experiences in the Military.

8 Where is that? In front of this one. Well,
9 I don't have it in front of me now, but are you
10 familiar with that Wright Pattman study that was done
11 in 1990?

12 WITNESS THOMAS: Certainly. The tanks
13 themselves are designed -- I would say the wing itself
14 is the box that carries the airplane. It has to carry
15 air dynamic loads. The design features that go into
16 the tank itself are, (a) we have to assume and design
17 the tank for whatever pressures we can experience in
18 flight, which are typically relatively low, plus 3-1/2
19 psi minus 2 psi kind of numbers.

20 We design the tank to stand a refuel overflow
21 condition. I described the vent system. If we filled
22 the airplane at 55 psi pressure, this is not like
23 fueling your car that takes, you probably put 5 or 10
24 gallons into your car in a minute; we fuel these
25 airplane anywhere as high as 2,000 gallons a minute.

1 The volt top off system Mr. Taylor described
2 is intended to shut off that fueling system when the
3 tank gets full. If that system fails for whatever
4 reason, then we overfilled the tank, and the vent
5 system itself is sized to take that flow overboard out
6 through the vent system and out through the wing tip
7 without exceeding a tank bottom pressure.

8 We design the pressure drop for the vent
9 system so the tank itself only experiences something in
10 the order of -- it depends on the airplane we design,
11 but either 10 psi or 13 psi. The structures
12 requirement is to add a 1.5 safety factor on that which
13 gets you to the 20 psi kinds of numbers we talked about
14 earlier or yesterday.

15 so, we designed the tank for 20 psi. To
16 design the tank for a fuel tank explosion would mean
17 you would have to design the tank to be able to carry
18 well over 100 psi, which is not effective as an
19 airplane.

20 CHAIRMAN HALL: Thank you.

21 MR. SWAIM: Mr. Thomas, this is an
22 illustration of the air-conditioning equipment for
23 packs that are located below the center tank, and there
24 is a lot of ducting and some very hot components.

25 Are there differences in design or the

1 process of designing these fuel tanks that you were
2 just speaking of, between the center tanks and the wing
3 tanks, are there then the shape and the size in having
4 this heat from below the tank?

5 WITNESS THOMAS: There is no fundamental
6 design difference. We treat the tank exactly the same
7 way as we would treat any other tank. The design
8 features, as far as safety is concerned, the air that
9 comes from the engines to run these packs, we design
10 the system. There are pre-coolers on board the engines
11 to cool that air so that the air coming from the
12 engine, which is the hottest source of any air in the
13 airplane, is kept deliberately below 450 degrees
14 Fahrenheit.

15 Typically, it will run somewhere in the 350
16 range when it's normally running. So that is the
17 hottest temperature we have on board the airplane to
18 bring the ducts to the packs.

19 MR. SWAIM: Providing there is no failure of
20 the temperature controls?

21 WITNESS THOMAS: Including failures, we
22 design the system so that if the system fails on the
23 engine, we have sensors that step in and control and
24 shut down the system if the temperature goes over 500
25 degrees. So, we have a built-in protection feature to

1 make sure we do not exceed that 450 degree number.

2 We have discussed at length the temperatures
3 on the box of the center wing tank, do not exceed our
4 390, and so there is no reason to design the center
5 tank to be any different from a wing tank.

6 MR. SWAIM: Okay. Then based on that, since
7 the fuel probes are similar, different lengths, but
8 fairly similar, and the other components are
9 essentially the same, why did your inspection bulletins
10 since the accident only addressed the center tanks and
11 none of the other tanks?

12 WITNESS THOMAS: The first -- I pass that to
13 Jerry.

14 MR. HULM: The primary concern and the focus
15 of the investigation has been the center tank of the
16 747, and it's mostly due to its exposure, much longer
17 exposure period to the flammable fuel air mixture. So
18 that's why we are addressing specifically at this point
19 with our inspection bulletin the center fuel tank.

20 There is an industry group that has been
21 formed, and their intent has been announced, but it's
22 composed of over 60 airlines and air associations, all
23 the major aircraft manufacturers, including Boeing,
24 Lockheed and Air Bus, and the purpose of this industry
25 working group is to put together an extensive

1 inspection program to assess the condition of fuel
2 tanks, not just center tanks on these airplanes, but
3 also the main tanks.

4 The primary purpose of that is to assess
5 their condition and be able to provide an enhanced
6 maintenance operational or design features for the
7 airplanes. So, right now, the real focus has been on
8 the center tank, and that's probably our primary
9 concern, but we are going to be addressing all the
10 other tanks, not, and not just on Boeing models, but
11 worldwide.

12 DR. LOEB: Mr. Hulm, you indicated that this
13 was primarily because of the longer exposure to
14 flammable vapors in the center tank; is that what I
15 understood you to say?

16 MR. HULM: Correct.

17 DR. LOEB: That's because of what?

18 MR. HULM: That's just because of the pack
19 bay heating up the tank.

20 DR. LOEB: So that because of the pack bay,
21 the packs underneath that provide the heating into the
22 tank, you have a flammable vapor for a much longer
23 period of time than you do in the wing tanks where you
24 don't have that?

25 MR. HULM: Correct.

1 DR. BIRKY: What is the schedule for this
2 inspection program you're talking about on the tanks?

3 MR. HULM: Right now, the industry group
4 formed officially just earlier, just a couple of months
5 ago. The inspection program is supposed to last over
6 the next two-and-a-half years. We have already begun
7 work on developing the maintenance instructions to the
8 airlines to inspect the airplanes that will follow very
9 closely what we've done for the center tank inspection
10 bulletin.

11 DR. BIRKY: Is the FAA involved in that
12 program to get feedback?

13 MR. HULM: My understanding is, the FAA has
14 been invited. Maybe Mr. Cheney would want to address
15 that directly.

16 WITNESS HARTONAS: The FAA is participating
17 in the review of the Boeing Service Bulletin of
18 Inspections, associated with a bulletin --

19 MR. SWEEDLER: I'm sorry, I can't hear you.

20 WITNESS HARTONAS: The FAA is involved in
21 reviewing the Boeing Service Bulletins and inspections
22 associated with the Service Bulletin. The FAA is at
23 this time considering making those bulletins mandatory.

24 DR. BIRKY: But does that mean you are or are
25 not participating in the special inspection program

1 with the industry?

2 WITNESS HARTONAS: The answer to that is,
3 yes, we're participating.

4 MR. SWAIM: Very good. The next question
5 that I have is regarding temperatures. We have been
6 talking about the air-conditioning pack located beneath
7 the center tank. This is just the forward half of one.
8 At the far end of that bay is actually one end of a
9 great big radiator. You are still missing the other
10 body, the radiator and the rest.

11 SO, that's the source of the heat we're
12 talking about. There is no insulation between that and
13 the tank above.

14 What are the usual problems with fuel
15 temperature? Why do we have fuel temperature
16 indicators installed for fuel tanks?

17 Mr. Cheney?

18 WITNESS CHENEY: The current temperature
19 indication system that's installed on transport
20 airplanes involves the protection of the fuel from a
21 pumpability standpoint. In flight, particularly, the
22 long duration flight, the fuel can get very, very cold,
23 and the indication of that cold state can allow the
24 flight crew to either descend or increase total air
25 temperature, speed up.

1 And that's not commonly necessary, but as the
2 airplanes get longer and longer ranges, particularly in
3 the outboard portions of the wing, that fuel can get
4 very cold. It can approach the freeze point of the
5 fuel .

6 MR. SWAIM: What other problems can come up
7 then? For example, if we do have hot fuel, what kind
8 of problems could that induce?

9 WITNESS CHENEY: The other extreme is the
10 pumpability at the high temperature end, and for these
11 aircrafts, they have been evaluated at what is an FAR
12 requirement of hot fuel testing, which is, each fuel
13 that is eligible to be used has to be evaluated to at
14 least 110 degrees Fahrenheit, and in most of the Boeing
15 products, the upper fuel temperature limit is 120 or
16 130 degrees.

17 The objective of that is to show that you
18 don't have an unacceptable liquid the vapor ratio being
19 delivered at the engine. In the case of the center
20 tank, while it is true that the center tank itself may
21 be higher than the outboard wing tank where the probe
22 is located, by the way in which the fuel feed is
23 conducted, you never have that fuel able to exhaust
24 fuel to the engine. When you are feeding from that
25 tank, you are also feeding main tank fuel.

1 SO, even if you were to cover up the inlets
2 of the pump pick ups in the center tank, you have main
3 tank pumps on, which are going to be at lower than 130
4 degrees. So, there has never been a concern for fuel
5 starvation at the engine. In the service experience of
6 the airplane, there is no evidence of that.

7 MR. SWAIM: Even so, there is a written
8 requirement in the Airplane Flight Manual, and there is
9 a reference, Exhibit 9C, page 107, it tells the flights
10 crews, do not use fuel above a certain temperature, but
11 they are not provided with a means of telling the
12 temperature.

13 WITNESS CHENEY: They are. That's the
14 temperature gauge that's in the outboard tank, and
15 that's what has been used for the entire time these
16 airplanes have been in service, and it's been used very
17 well in the hottest environments on the planet. Fuel
18 supply at the engine has not been a concern. If that
19 were an issue that we felt could impact safety, that
20 would be the subject of corrective action. We would
21 have a probe relocation to the higher part of the tank.

22 MR. SWAIM: So, are you saying that you had
23 measured the temperatures at the tank previously? You
24 knew what the temperatures were coming out, and
25 therefore, knew that they were dropping to get to that

1 indicator going into the engine?

2 WITNESS CHENEY: No, they weren't measured
3 previously, but what I'm describing is the way in which
4 the fuel system is supplying fuel to the engines. When
5 the fuel pumps in the center tank are on, so are the
6 fuel tanks simultaneously on in the wing tanks. If
7 there is any interruption in the center tank fuel, the
8 wing tank pumps will provide constant liquid to the
9 engines. So, there is not a concern by the way in
10 which the fuel system is arranged currently.

11 MR. SWAIM: My question, Mr. Thomas, there is
12 a temperature rise mentioned in the operator's manual
13 of the airplane for the crews, the pilots. How did
14 Boeing know the temperature rise of the center tank to
15 put into that manual? I'm going back to, have you
16 previously done temperature testing in the center tank
17 to know that?

18 WITNESS THOMAS: I'm not personally aware of
19 what we did. I would presume that we did some kind of
20 flight test at some point to measure the temperature of
21 the fuel itself.

22 As Mr. Cheney said, the issue here is not
23 whether the center tank was flammable; it is a function
24 of, is the fuel hot enough to run into captation
25 problems and disrupt engine feed. The notes in the

1 flight manual are really intended to provide advice and
2 guidance to the crew that the center tank fuel itself
3 may be warmer than the fuel in the wing tanks.

4 so, they understand that phenomena, but it's
5 an engine feed pump captation concern, not anything to
6 do with flammability.

7 CHAIRMAN HALL: Could I get back to this
8 inspection program just very briefly?

9 MR. SWAIM: Please.

10 CHAIRMAN HALL: on the two-and-a-half year
11 inspection program, is that what Boeing has for 747s,
12 or is the inspection program any different than the
13 747, time table?

14 WITNESS CHENEY: The time table is for the
15 entire fleet, including the 747 airplane, so the 747
16 center tank inspection is the leader on this issue.

17 CHAIRMAN HALL: And there are 970/747s; is
18 that correct?

19 WITNESS CHENEY: It's pretty close to 1,000,
20 yes.

21 CHAIRMAN HALL: Close to 1,000. And is there
22 any priority in doing that in terms of the age of the
23 airplane, or is it just when they're -- what does the
24 language of the service bulletin direct the operator to
25 do?

1 WITNESS CHENEY: The language in the service
2 bulletin states that the next heavy maintenance of the
3 airplane.

4 CHAIRMAN HALL: Which is?

5 WITNESS CHENEY: it depends on the airline
6 and when they consider was heavy maintenance.

7 CHAIRMAN HALL: What would be the longest
8 period of time? Would it be within two-and-a-half
9 years, or could it be longer than two-and-a-half years?

10 WITNESS CHENEY: It could be; it could be
11 longer than two-and-a-half years.

12 CHAIRMAN HALL: SO, if it's longer than two-
13 and-a-half years, would they still have to do it or
14 not?

15 WITNESS CHENEY: Right now, there is no
16 mandate to accomplish that.

17 CHAIRMAN HALL: SO, if the industry tells all
18 of us that this is being done in two-and-a-half years,
19 that's not really what Boeing has directed; is that
20 correct?

21 WITNESS CHENEY: We're inspecting airplanes.
22 We did not specify all airplanes. We are inspecting a
23 subset of those airplanes in that two-and-a-half year
24 period. I'm sorry. We're not inspecting every single
25 airplane, every single tank in the two-and-a-half

1 years.

2 CHAIRMAN HALL: Are you inspecting all the
3 classics?

4 WITNESS CHENEY: Right now, the way we're got
5 our service bulletin written, we say, at the next
6 opportunity during heavy maintenance are within two
7 years. That's the way our service bulletin is written.
8 That's the recommendation to the airline.

9 MR. SWAIM: Approximately, how many airplanes
10 is that?

11 WITNESS CHENEY: That covers the entire 747
12 fleet.

13 DR. LOEB: Could you just clarify for the
14 record what service bulletin you were referring to?

15 WITNESS CHENEY: This a center wing tank
16 inspection service bulletin. The purpose behind this
17 bulletin is to enter the center tank itself, to look at
18 all of the wiring, all of the probes, look at all the
19 equipment in the center tank, look at all the mounting
20 straps, term and condition of it; look for any damage,
21 and also an extensive check of all the bonds and
22 grounds within that tank.

23 CHAIRMAN HALL: What is the quickest service
24 bulletin Boeing has ever issued?

25 WITNESS CHENEY: I don't know the answer to

1 that question.

2 DR. LOEB: Let me just go back. This is a
3 service bulletin that has been issued, or is being
4 worked on now?

5 WITNESS CHENEY: This has been issued in July
6 of this year.

7 DR. LOEB: That's what I thought, and there
8 is a --

9 CHAIRMAN HALL: Excuse me, Dr. Loeb.
10 Are any 747s being inspected as we're sitting
11 here today, or not?

12 WITNESS CHENEY: Yes, sir, they are.

13 CHAIRMAN HALL: Can you tell us which ones?

14 WITNESS CHENEY: We have 52/747s that have
15 been inspected up to this point in time.

16 CHAIRMAN HALL: Part of the service bulletin?

17 WITNESS CHENEY: For the service bulletin.

18 CHAIRMAN HALL: Into the tank?

19 WITNESS CHENEY: Into the tank.

20 CHAIRMAN HALL: Fifty-two of 970?

21 WITNESS CHENEY: Correct.

22 CHAIRMAN HALL: And how many of those are the
23 classic?

24 WITNESS CHENEY: I don't have the number at
25 the top of my head.

1 CHAIRMAN HALL: Could you provide that for
2 the record? I would appreciate it.

3 WITNESS CHENEY: Yes, I could.

4 CHAIRMAN HALL: But I'm still trying to
5 understand; does the service bulletin require this to
6 be done within two years, or is it required to be done
7 at the next heavy maintenance check which may or may
8 not be within two years?

9 WITNESS CHENEY: The way our service bulletin
10 is written is that we recommend that they do it within
11 -- during their next heavy maintenance or within two
12 years. All we can do is make a recommendation to the
13 airlines.

14 CHAIRMAN HALL: So, it's a recommendation;
15 not a requirement?

16 WITNESS CHENEY: Correct.

17 CHAIRMAN HALL: And the FAA has not made it a
18 requirement, but it's considering it and looking at
19 that; is that correct, Mr. Cheney?

20 WITNESS CHENEY: Well, currently, our
21 understanding is, this bulletin is being revised, and
22 it's being revised based on knowledge it's gained from
23 these early inspections, and currently, our plans are
24 to require this inspection on all 747s.

25 CHAIRMAN HALL: Well, I just appreciate you

1 gentleman, and I appreciate the industry and the things
2 represent, the Boeing Company, but, you know, it's 16
3 months since this accident occurred, and to be sitting
4 here and saying we're going to do something that takes
5 16 months and add two-and-a-half years and it's just a
6 recommendation, I get criticized for being frustrated,
7 but, to me, that's frustrating.

8 How many classic 747s are there? We know
9 that this accident occurred with a classic 747; is that
10 correct? I know that's correct. So, do we know how
11 many classic 747s there are?

12 WITNESS CHENEY: I believe there's
13 approximately 750.

14 CHAIRMAN HALL: Of the 970?

15 WITNESS CHENEY: Correct.

16 CHAIRMAN HALL: So when you're talking about
17 the classics, you're talking about the majority of the
18 fleet?

19 WITNESS CHENEY: Correct.

20 CHAIRMAN HALL: Okay.

21 Please proceed.

22 DR. BIRKY: I'd like to follow that up a
23 little bit, if I could, in terms of that inspection
24 process. That is just a visual inspection; is that
25 correct, no measurements?

1 WITNESS CHENEY: No, that's incorrect. There
2 are measurements made of all the bonding and grounding
3 within that tank.

4 DR. BIRKY: How about on the fuel probes?

5 WITNESS CHENEY: No, there are no
6 measurements of the fuel probes, and that's one of the
7 things that we're going to be doing as part of the
8 revisions of the service bulletin, is adding a check of
9 the fuel probes themselves, into the wiring in the
10 tank.

11 DR. BIRKY: And a check will be a
12 measurement, electrical measurement?

13 WITNESS CHENEY: Yes, it will be an
14 electrical measurement, insulation resistance test.

15 CHAIRMAN HALL: Let me try to understand one
16 other thing now. If the manufacturer of this Boeing 747
17 puts out a service bulletin, how does the FAA deal with
18 in terms of an AD? How long does that take? Because
19 obviously, what we're being told is, that a service
20 bulletin is a recommendation, not a requirement, and
21 for flying in this country, we look to the FAA for the
22 regulations for safety.

23 SO, what is the process? Are you waiting
24 until a recommendation, the service bulletin comes out,
25 to consider it? Are you with your DERs involved in

1 that process so if it was a safety issue, that you
2 could move simultaneously, and when did you begin
3 working on this particular service bulletin in terms of
4 regulation, if you know, Mr. Cheney?

5 WITNESS CHENEY: Well, as you aware, there
6 are issues that are unfolding on this investigation,
7 and have been unfolding late summer and this Fall.

8 CHAIRMAN HALL: What has not changed is, that
9 we had a 747 explode. We agreed early on that the
10 center fuel tank was the cause, is what brought the
11 aircraft down. That hasn't changed or revolved, and
12 what has not changed is, we don't know what the
13 ignition source was. so, what I'm trying to do is,
14 find out what has Boeing done? That's why I'm asking
15 you all this in a public setting, a public record, what
16 has Boeing and the FAA done since we don't know to try
17 to take prudent steps so that fault tree is in place to
18 be looking at every possibility that could have caused
19 this accident, so that when I'm asking the question,
20 "Mr. Chairman, should the people be flying the 747?", I
21 can answer, as I try to do, you, know, "Yes. The
22 industry and the FAA, the government regulators, we
23 don't know what caused this accident, but we're doing
24 everything that you would do or I would do in those
25 situations to prudently protect the American public."

1 so, if you gentlemen could tell us what
2 you're doing, that's what I'd like to know.

3 WITNESS CHENEY: Well, I can address some of
4 that, you know, what we've done since the accident, you
5 know, the service bulletin is just one action of that.
6 We have done an extensive review of all the components
7 that are involved in the system from top to bottom over
8 the last year-and-a-half. We haven't been idle. It's
9 been a very extensive review.

10 It's involved a lot of people within Boeing
11 and Honeywell, within different parts of the industry,
12 and looking at all these parts, try to determine this
13 accident, what could have been the cause? We do have
14 the fault tree. We've gone through that, and the NTSB
15 has looked at that.

16 We've got the inspection program not only for
17 the center tank, but we addressed the fuel boost pump
18 issue with the wiring and the conduits, and we have
19 done a complete inspection of all U. S. registered
20 aircraft for that conduit, making sure that the
21 sleeving that is protecting that wiring is intact, and
22 we have verified that that's okay.

23 We have also got the issue with the scavenge
24 pump connector that the NTSB brought to our attention
25 during a tear down of an auto service scavenge pump,

1 and we released a service bulletin on that, and the FAA
2 has ADed that service bulletin that's currently being
3 implemented.

4 We've got the on-going inspection of the
5 boost pumps themselves, which was prior to the
6 accident, but that is still kind of involved in this.
7 We have been look at that very closely. We have done a
8 lot of static testing in our laboratories, as far as
9 looking at all the different components that are in the
10 tank, determine what their static charge build-up, make
11 sure we have adequate bonding and grounding for it;
12 making sure there wasn't some source that we missed. A
13 lot of that work was done with the NTSB. They have
14 looked at that.

15 CHAIRMAN HALL: How many service bulletins
16 have come out of all that work?

17 WITNESS CHENEY: The scavenge pumps are in
18 that bulletin. We had the service bulletin for the
19 conduit inspections. We've got the center tank
20 inspection service bulletin.

21 CHAIRMAN HALL: And how many of those are
22 ADs?

23 WITNESS CHENEY: The conduit AD was issued
24 almost a year ago, and we recently superseded that to
25 expand its affectivity to all 747s. We've issued an

1 MPRM that will require shielding and/or a search,
2 suppression systems on all 747 center tanks, and that's
3 in the comment period now.

4 We do plan to take mandatory action on the
5 center tank inspection when all of the issues are
6 included in that. We are very concerned about multiple
7 entries to this tank. We want to enter it one time and
8 do the right things one time; fix the things that we
9 believe should be fixed, and fix them right.

10 The current schedule of having that bulletin
11 is --

12 CHAIRMAN HALL: And you don't think that
13 Boeing's service bulletin does that?

14 WITNESS CHENEY: Not yet. There are things
15 that are being added, and that's the revision. There
16 are components within that tank that need to be looked
17 very carefully at, and the current bulletin simply
18 doesn't do that.

19 CHAIRMAN HALL: Now, if we had a situation
20 where the FAA wanted to order an inspection of all the
21 classic fleet, how long do you think that would take
22 for the ones that operate in this country, Mr. Cheney?

23 WITNESS CHENEY: We'd have to decide the
24 issue that we're looking into, is this a scenario --

25 CHAIRMAN HALL: What's the shortest AD that

1 you all have ever put out?

2 WITNESS CHENEY: We've had ADs that have
3 stopped airplanes from flying; that's the shortest.
4 And others will go a year or two, depending on things
5 like the availability of the aircraft, getting into
6 that part of the airplane. We have to consider the
7 entire impact of the action.

8 CHAIRMAN HALL: I understand that, but I also
9 hope you will impact upon you the urgency, I think,
10 that at least myself - let me speak for myself - and I
11 think I reflect, to some degree, the American traveling
12 public has in this issue. So, I would hope that would
13 be factored in, as well.

14 WITNESS CHENEY: And we agree.

15 DR. LOEB: Mr. Cheney, or Mr. Hulm, do you
16 have that target date now for the revised service
17 bulletin on the inspection of the tank and probes?

18 WITNESS CHENEY: January of next year.

19 DR. LOEB: And Mr. Cheney, is it likely that
20 you will go directly to a final rule on this, or is
21 this likely there will be some sort of -- in other
22 words, to issue an AD rapidly as soon as it's done?

23 WITNESS CHENEY: I am not able to answer
24 that. There are several more people that are going to
25 be involved in that decision than myself; but, it will

1 be an aggressive action.

2 CHAIRMAN HALL: Mr. Hulm, what has been
3 learned from these inspections, so far?

4 MR. HULM: The data we have collected from
5 the inspections is really targeted toward the -- right
6 now, it's the quantitative data on the bonding and
7 grounding in the fuel tank itself. There are
8 approximately about 2,000 different measurements that
9 are taken. I have to be careful with that number.
10 Let me check that again.

11 But there are a large number of measurements
12 that are taken on all the different static bonds within
13 and all the different current bonds that we have for
14 the equipment. To this date, we have not run across
15 anything that would represent an admission source in
16 any of our fuel tanks.

17 MR. ELLINGSTAD: Could I follow-up very
18 quickly on that. You've talked about the separate
19 measurements that have been taken. Are you focusing on
20 these faults with respect to individual components, or
21 some of these measurements apply to the entire system
22 with respect to the opportunity for higher voltages, et
23 cetera?

24 MR. HULM: These measurements that we're
25 taking are just stuff like the bonding and grounding

1 straps on the tank, you know, the stuff that goes
2 around the fuel tubes.

3 MR. ELLINGSTAD: With respect to individual
4 components, rather than a system level evaluation.

5 MR. HULM: Well, no. It is individual
6 components. It's just like the bonding straps on the
7 pumps and the bonding straps on the valves and the
8 bonding straps on the tubes themselves, the fuel tubes
9 that are in the tank; so it addresses individual
10 components.

11 As far as the FQ components right now, it's
12 just a visual check in the airplane, and it's not
13 totally complete, and that's one of the things that Mr.
14 Cheney alluded to that we're going to be adding to that
15 service bulletin. It is a more detailed inspection of
16 all of those components. When we get the data
17 necessary back, so we can determine what the conditions
18 of those are.

19 CHAIRMAN HALL: Maybe Ms. Rodriguez might
20 help you with this, but I would be interesting in
21 knowing, does your service bulletin cover the 747s that
22 are part of the Military fleet, such as Air Force 1?

23 MS . RODRIGUEZ: If there is a service
24 bulletin issued or an AD, we do it.

25 CHAIRMAN HALL: Do you treat it as a

1 recommendation, or do you do it?

2 MS . RODRIGUEZ : We do it.

3 CHAIRMAN HALL: Is that an Air Force
4 requirement?

5 MS . RODRIGUEZ : Military.

6 CHAIRMAN HALL: It's a Military requirement?

7 MS . RODRIGUEZ: We do it within the time
8 frame.

9 CHAIRMAN HALL: What about the service
10 bulletin that is out now; what is the effect of that as
11 it pertains to the Military 747 Fleet?

12 MS . RODRIGUEZ: I don't have the data to
13 answer that.

14 CHAIRMAN HALL: Could you please get that for
15 me and provide it for the record? Either you or Mr. --
16 well, you need to do that because you're representing
17 the Military here.

18 MR. RODRIGUES: Mr. Chairman, may I ask a
19 question from Boeing?

20 CHAIRMAN HALL: Yes.

21 MR. RODRIGUES: The Boeing table? The Boeing
22 table, Mr. Chairman?

23 CHAIRMAN HALL: Yes, sir. I'm sorry.

24 MR. RODRIGUES: We do have that answer. That
25 airplane was inspected, completed.

1 CHAIRMAN HALL: So Air Force I has been
2 inspected?

3 MR. RODRIGUES: Yes, Mr. Chairman.

4 CHAIRMAN HALL: Thank you.

5 DR. BIRKY: Yes. I have one follow-up
6 question that I would like to ask Jerry Hulm.

7 When these tanks are inspected, where does
8 this data go? Who possesses the data?

9 MR. HULM: Right now, the service bulletin
10 instructs the airlines to return the data to Boeing for
11 our analysis.

12 CHAIRMAN HALL: Mr. Swaim, let me just say
13 that, in fairness, we need to move to the party tables
14 if we're going to continue the technical panel, the
15 Chairman and everybody up here talking so much, we need
16 to be sure the parties have a chance.

17 so, if you all could sum up, if we need to
18 come back to the technical panel, we will do that, but
19 I'd like to get to the parties because in fairness, I
20 want to be sure they have an opportunity to question
21 and raise any issues they want to, as well.

22 MR. SWAIM: Absolutely, sir. We will be
23 continuing. We diverged quite a bit in this panel into
24 tomorrow's ignition sources type questions. Maybe we
25 will cut that panel a little shorter.

1 CHAIRMAN HALL: Don't count on it.

2 (Laughter)

3 MR. SWAIM: It is a good opportunity for us
4 to sum up and pass the questions down the table, if any
5 of the other technical panel members have any further
6 questions at this time.

7 CHAIRMAN HALL: Let Mr. Haueter have one
8 question, and then we will move to the parties.

9 MR. HAUETER: I just have a quick one. Mr.
10 Cheney, FAA: There are many designs up there with
11 center fuel tanks that also have potential ignition
12 sources. Is there any inspection that's going to be
13 done of these other aircraft?

14 WITNESS CHENEY: I believe the plans that
15 were described in the letter from the Administrator to
16 the Board discussed the issuance of a special Federal
17 Aviation regulation that is going to require each type
18 certificate holder of a transport airplane to develop a
19 maintenance program for the fuel system, and this would
20 include pumps, wires, probes, everything we've been
21 discussing about this morning.

22 Each operating certificate holder to
23 implement a maintenance program; it's becoming clear,
24 and has been clear to us throughout this investigation
25 that tank maintenance hasn't been a high priority issue

1 fleet-wide. It's something that we plan to take action
2 on, but it's going to apply to more than just the 747,
3 and more than just the Boeing fleet.

4 MR. HAUETER: Thank you, sir.

5 CHAIRMAN HALL: Mr. Hulm, you stated that the
6 970 planes that - what was the number you said - that
7 have been inspected?

8 MR. HULM: Fifty-two.

9 CHAIRMAN HALL: And you found no ignition
10 sources on these inspections?

11 MR. HULM: Correct.

12 CHAIRMAN HALL: Did you find any
13 abnormalities or any problems as a result of the
14 inspections?

15 MR. HULM: What we have seen is that in our
16 design requirements in the original manufacture of the
17 bonds and grounds that are on the airplane, we specify
18 a certain limit, and that limit is designed, you know,
19 it has a little bit of a buffer run into it. And what
20 we have done as part of the inspection bulletin, we
21 say, well, if it's outside of the original
22 manufacturing limit that they have to rework the bond
23 to bring it back down to what was originally designed
24 by the manufacturer.

25 SO, what we have seen is that these values

1 have drifted somewhat above that, but we haven't seen
2 any drift above where we would consider we'd have an
3 ignition source in the tank, or a problem. We have
4 identified some areas, and the airlines are aware of
5 these, where some components are drifting more than
6 others, and those take rework, and that's what they're
7 looking at.

8 CHAIRMAN HALL: Okay. Just for planning
9 purposes, according to the Chairman's watch, which is
10 the operational watch, it's 12:05:51. We will go until
11 1 p.m., and then we will take an hour break for lunch,
12 and return. So that way, everybody can make their
13 plans and know what's going on.

14 Now, I think I left off yesterday, Capt.
15 Young, you were first yesterday; right? So, it's Mr.
16 Streeter's turn with the Federal Aviation
17 Administration.

18 Mr. Streeter?

19 MR. STREETER: Thank you, Mr. Chairman.

20 I'd like to start off for Mr. Thomas.

21 Earlier, there was some discussion by the Board
22 regarding the use of less volatile fuel, such as, JP-5.
23 Is it the case right now that JP-5 is an approved fuel
24 for any Boeing commercial airplanes?

25 WITNESS THOMAS: As far as I know. I cannot

1 answer that question at this point. I know it was
2 approved against the normal ASTM, Jet-A, Jet-A1 fuels,
3 JP-8 . JP-5 is, as we discussed earlier, U. S. Navy
4 fuel for carrier operation. I'm not aware that we have
5 specifically certified airplanes for JP-5. I can
6 certainly take that as an action item to verify that.

7 MR. STREETER: Would that be acceptable to
8 the Chairman for Boeing to provide that for the record?

9 CHAIRMAN HALL: Yes, if you please. Well,
10 it's certainly understandable, and so many questions
11 asked, if you don't the exact information, I'd
12 appreciate it, Mr. Swaim, if you would follow up since
13 this is your group here, and get that answer for the
14 record.

15 Thank you.

16 MR. STREETER: And also for Mr. Thomas, you
17 did mention the boost pumps with a 35,000 hour life.
18 What happens at that point? Are they retired, or can
19 they be overhauled?

20 WITNESS THOMAS: That would depend on the
21 airline themselves. They would overhaul them or
22 whatever process they would use.

23 MR. STREETER: So, the option is, according
24 to their maintenance program; is that correct?

25 WITNESS THOMAS: Yes.

1 MR. STREETER: For Mr. Cheney, just to
2 clarify a point here: I think Boeing very graciously
3 pointed out that they invite the FAA to their testing.
4 Do you need to wait for an invitation?

5 WITNESS CHENEY: No, we do not. They are
6 FAA tests, and we jointly conduct them.

7 MR. STREETER: Okay. Thank you, sir.

8 And again, for Mr. Cheney, I'd like to go
9 back to the issue that has been discussed to some
10 extent about the basic design assumption that the fuel
11 mixture will always be flammable in the tank for design
12 purposes.

13 Can you characterize how that assumption has
14 been used for purposes of safety in design
15 consideration?

16 WITNESS CHENEY: Well, like I mentioned
17 earlier this morning, that assumption has been with
18 Aviation since Aviation began, and as transport
19 airplanes have become more and more numerous, more
20 popular, that assumption of flammable vapor has been
21 successful, but not successful enough.

22 We are looking at ways to prevent tank
23 explosions, and if an avenue, such as, reducing or
24 eliminating the flammable vapor can lead to that end,
25 then we are very much in support of that.

1 MR. STREETER: All right. Thank you, sir.

2 This is for anybody on the panel because we
3 were tossing around some numbers there that might not
4 be easily understood. I believe there was a definition
5 there where we were talking about a 20 microjewel
6 spark.

7 Can someone relate that to something that
8 people in the audience can relate to? For example,
9 dragging my feet across the carpet and ending up with a
10 static spark; how does it relate to that?

11 MR. DICKINSON: I believe this would be the
12 wrong forum for that, Mr. Streeter.

13 DR. BIRKY: Well, I can answer the question
14 if you want an answer.

15 MR. STREETER: Answer the question, please.

16 DR. BIRKY: Well, a quarter of a millijewel
17 is if you take a dime and hold it about one inch off
18 the table and drop it, that's a quarter of a
19 millijewel. You're talking about 20 microjewels, which
20 is a factor of 10 less than that. So, if you hold up,
21 oh, 5 inches off the table and drop it, that's the
22 amount of energy you're talking about.

23 Does that answer your question?

24 MR. STREETER: Well, no, but then, again, it
25 may not be that easy to answer. Thank you for trying

1 anyway.

2 MR. HULM: The only other example that I
3 have, maybe is, if you look at a standard 60 watt light
4 bulb that you have in your house, and that light bulb
5 is consuming energy as it's burning. The amount of
6 energy in .02 millijewels is how much is consumed by
7 that 60 watt light bulb is less than a millionth of a
8 second. It's a very, very small amount of energy.

9 MR. STREETER: Thank you. That, I think, is
10 something I can relate to.

11 And for you, Mr. Hulm, regarding the fuel
12 tank inspection service bulletins and your mention that
13 they were being revised at this time, are those
14 revisions being undertaken based on findings in the
15 accident investigation, or findings in the initial
16 inspections?

17 MR. HULM: It's a combination of both. There
18 are some clarifications that need to be made to the
19 bulletin, and the airlines had pointed it out to us as
20 they have been implementing the bulletin on the
21 airplanes. There are some of the things that the NTSB
22 has pointed out shown during their investigation as far
23 as some of the wire outing problems that they noted,
24 and those will be adding enhanced instructions for
25 inspecting probes, and the wiring of those probes.

1 MR. STREETER: And then one minor small point
2 here, except I'm no really sure whether it got
3 clarified. There was some discussion back and forth
4 about information in the airplane flight manual on fuel
5 temperatures. Can you clarify for me that there is
6 indeed a temperature gauge there for the crew to read
7 out the fuel temperature, at least in one tank?

8 WITNESS THOMAS: Yes, there is a fuel
9 temperature, particularly in the outboard main tank on
10 the 747 or the main tank of a 57 of 67 or 77.

11 MR. STREETER: With a readout in the cockpit?

12 WITNESS THOMAS: Correct.

13 MR. STREETER: Thank you very much, and
14 that's all the questions I have, sir.

15 CHAIRMAN HALL: Thank you.

16 The Boeing commercial airplane group.

17 Mr. Rodrigues?

18 MR. RODRIGUES: A couple of questions. For
19 Mr. Hulm: Earlier in this panel, the question was
20 raised regarding how many ignition sources there are in
21 the center tank, and subsequent to that, there was lots
22 of discussion about the fault tree and so on, and I
23 think it got answered there.

24 Do you feel that you know, understand how
25 many various -- not how many -- but do you understand

1 the various ignition sources that are available in the
2 tank based on the development of the fault tree?

3 MR. HULM: The system is designed that there
4 are no ignition sources in the tank. The analysis that
5 we do under examining the different failure modes that
6 can occur, basically details what could happen in a
7 tank, to the best of our knowledge; and the design
8 precludes ignition sources.

9 SO, to state what ignition sources are in the
10 tank, there are no ignition sources in the tank.

11 MR. RODRIGUES: Okay. Next question. A
12 question was also asked, what's been done subsequent to
13 TWA in terms of work that Boeing has done? And you
14 discussed earlier the inspection bulletin.

15 This should be directed to Ivor Thomas: What
16 specific design studies has Boeing started in an
17 attempt to lower the flammability exposure of the
18 center tank?

19 WITNESS THOMAS: When the accident happened,
20 and the full subject of flammability inside the center
21 wing tank came up in very early discussions with Dr.
22 Birky and ourselves, we proceeded to develop a computer
23 model by which we used to try and analyze what are the
24 temperatures in the center wing tank?

25 We have used that model. I think we

1 developed the model as far back as Christmas of last
2 year, if not, before that. We have used that model
3 extensively to look at alternatives. The NTSB has
4 proposed alternatives. We have attempted to use that
5 computer model to look at all of those alternatives,
6 plus others, and we thought about our own and
7 suggestions from outside the Boeing Company.

8 We take reducing the flammability of the
9 center wing tank very seriously. I think if this
10 hearing had been held five years ago, we would have
11 been chasing ignition sources. Now, we're shifting
12 gears and we're saying, we need to look at
13 flammability, as well, and I think it's a very
14 important point to register in this hearing.

15 I read several of the accident investigation
16 reports prior to this hearing, and it's very clear that
17 the focus of the industry in total was eliminating the
18 ignition sources, eliminating spots. This is the first
19 time we have really sat back and said, we need to look
20 at flammability, as well.

21 Currently, we took the opportunity when NTSB,
22 as I said earlier, when the NTSB flew the Evergreen
23 Airplane in July, and we took the opportunity to
24 piggyback on that; flew three flights of our own to get
25 more data to update the computer model.

1 One of the issues we realized early on was,
2 we did not have enough data to really feel like the
3 model was giving us correct data to really feel like
4 the model was giving us correct answers. We wanted to
5 really feel like the model was giving us correct
6 answers, and we wanted to explore that. We obtained a
7 lot of data from that flight test. We upgraded the
8 computer model, and we are now using it on a regular
9 basis.

10 At the same time, on that flight test, we
11 took the opportunity to attempt a very crude pack bay
12 cooling scheme where we simply provided some extra air
13 coming into the pack bay and learning there were five
14 or six holes in the back of the pack bay and just let
15 the air out. I measured all the temperatures in the
16 pack bay to see what happened. That was not
17 particularly effective, but it did give us a lot of
18 data as to what was going on, which was very valuable.

19 We are currently looking at schemes to
20 implement some kind of cooling process on the underside
21 of the tank. There is one scheme which we have
22 currently called slot cooling, which is just simply
23 providing an air gap underneath the center wing tank
24 and blowing some cold air through that slot.

25 That looks to be very effective. We' ve

1 looked at JP-5 and similar kinds of raising the flash
2 point, and combinations of these things. And that's
3 one advantage of the computer model. We can say, well,
4 what happens if we do this, this and this; what is the
5 effect? We're using it that way.

6 Sweeping was interesting. It certainly
7 wasn't our idea. It came from somewhere - I'm not even
8 sure where it came from - but it was definitely an idea
9 that would say, if we could keep the volatiles from
10 coming into the outage, can we in fact do some good
11 that way? We already have a lab test doing that. We
12 are still exploring it.

13 The biggest problem with that that we see is
14 the tendency for the air to flush too much fuel vapor
15 overboard. If you run this system too fast, you keep
16 the outage lean, but you start pumping an awful lot of
17 hydro problems overboard, and you think the EPA,
18 there's a lot of atmospheric pollution issues
19 associated with it, so we're still studying that.

20 Does that answer your question?

21 MR. RODRIGUES: Yes, it does.

22 Final question for Mr. Hulm: You discussed
23 the inspection bulletin. Could you distinguish between
24 the inspection bulletin and any modification bulletins
25 that are being considered?

1 MR. HULM: The primary purpose behind the
2 inspection bulletin is to inspect the airplane. If we
3 come up with something during that inspection, or even
4 as a result from the NTSB investigation here, we plan
5 to issue the appropriate modification bulletins to
6 correct the airplane so that we don't mix this
7 inspection bulletin up with any rework that's required,
8 and in that way we can kind of keep the two separate,
9 and it allows the FAA the independence of mandating
10 separate bulletins for correction as opposed to
11 inspection.

12 MR. RODRIGUES: Thank you.

13 That's all I have, Mr. Chairman.

14 CHAIRMAN HALL: Thank you very much.

15 The Airline Pilots Association - Captain?

16 CAPT. REKART: Thank you, Mr. Chairman.

17 I think Mr. Thomas, could you do me a favor,
18 please, and just clarify when you were talking about
19 the 50 degree margin of temperature, on which side of
20 the tank you're talking about that temperature being
21 measured; the inside of the tank, or the outside of the
22 tank?

23 WITNESS THOMAS: It's inside the tank.

24 DR. BIRKY: And even if it's filled with
25 fuel, it's still on the inside the tank with or without

1 fuel, it's on the inside of the tank?

2 WITNESS THOMAS: Yes. We use the 390 degree
3 Fahrenheit upper limit on any failure case that we
4 could have inside the fuel tanks. External of the fuel
5 tanks where it's a flammable leakage, though, we use a
6 number of 450 as a goal -- excuse me -- as a limit. I
7 beg your pardon.

8 CAPT. REKART: I believe that's what you said
9 earlier, but there was a previous reference that I
10 think left a little bit of doubt there, and I just
11 wanted to clarify that.

12 Mr. Chairman, Dr. Birky started to ask a
13 question a little while ago about the results of the
14 service bulletin and how that data was received and
15 distributed, and I'm sure he thought more about the
16 question than I have.

17 Could you let him ask that question, please?

18 CHAIRMAN HALL: Well, Dr. Birky, the Airline
19 Pilots Association designates you to ask a question for
20 them, so if there is no objection, proceed ahead.

21 Now, were you paying attention?

22 DR. BIRKY: Yes, sir, I was. As a matter of
23 fact, I wasn't clear about the question, because I
24 thought I asked that question, it was answered, that
25 is, where did the data reside, and who has possession

1 of that data from this inspection process.

2 Was that the one you were referring to?

3 CHAIRMAN HALL: And what was the answer?

4 MR. HULM: Boeing has that data. We're the
5 one who collected it and collated it. We showed that
6 to the FAA and at the initial working group meetings
7 that we had.

8 DR. BIRKY: So the FAA has that data now; is
9 that correct?

10 MR. HULM: That's correct. They've seen the
11 results of the inspections and up to this point in
12 time.

13 DR. BIRKY: And do they agree with the
14 assessment, there is no evidence of an ignition source
15 from that preliminary data?

16 MR. HULM: You have to let them answer that.

17 DR. BIRKY: Mr. Cheney?

18 WITNESS HARTONAS: The FAA has been
19 participating in meetings with Boeing in reviewing the
20 data that's coming from the field. The FAA also has
21 been participating in all investigative activities for
22 the Flight 800 accident.

23 The FAA has already taken proactive action
24 for the inspections of conduits in the fuel tanks for
25 the wiring. In addition, the FAA initiated AD action

1 for scavenge pumps before the service bulletin was
2 issued.

3 In addition, there is an MPRM that requires
4 additional protection on the airplane's wiring. As far
5 as the data that comes from the field in review with
6 Boeing, the FAA is evaluating that as it comes out, and
7 it's considering again the AD action for the
8 inspections .

9 CHAIRMAN HALL: I take that to mean that you
10 have not determined independently there are no ignition
11 sources, as Boeing says?

12 WITNESS HARTONAS: The FAA at this time is
13 planning on discussing this in the Ignition Source
14 Panel tomorrow. If he wants to address that, we can
15 proceed.

16 CHAIRMAN HALL: No. If that's going to be
17 discussed later, fine.

18 CAPT. REKART: I have no more questions, sir.
19 Thank you very much.

20 CHAIRMAN HALL: Thank you.
21 Honeywell, Inc.?

22 (No response)

23 CHAIRMAN HALL: Crane Company Hydro Air.

24 MR. BOUSHIE: Thank you, Mr. Chairman. Crane
25 has no questions.

1 CHAIRMAN HALL: Thank you.

2 The International Association of Machinists
3 and the Aerospace Workers.

4 MR. LIDDEL: Thank you, Mr. Chairman. We
5 have no questions.

6 CHAIRMAN HALL: And Trans World Airlines,
7 Inc.?

8 MR. YOUNG: Thank you, Mr. Chairman. At this
9 time, TWA has no questions.

10 CHAIRMAN HALL: Do any of the parties have
11 any follow-up or additional questions that they would
12 like to ask at this time before we proceed back to the
13 Technical Panel?

14 (No response)

15 CHAIRMAN HALL: Hearing none, does the
16 Technical Panel then have additional questions?

17 MR. SWAIM: Sir, I've been passed up a couple
18 of questions.

19 Have there been any scavenge pump ADs or
20 service bulletins that were applicable to the TW 800
21 air flight? And I guess I ought to pass that question
22 to Mr. Thomas or Mr. Hulm.

23 MR. HULM: The recent scavenge pump service
24 bulletin that was released was applicable to the TWA
25 airplane, but again, I think you have to understand the

1 particular problem with the scavenge pump was at the
2 connector itself and a part of the material in that
3 connector. That connector is still located within that
4 explosion-proof housing on the scavenge pump.

5 So, in relation to the accident, even though
6 the scavenge pump was indicated that it was off, that
7 really didn't have a bearing on that in that respect.

8 MR. SWAIM: So that's the only one applicable
9 to the airplane - that airplane, the airworthiness?

10 MR. HULM: Yes, as far as I know.

11 MR. SWAIM: Okay. Mr. Hartonas, for the
12 airworthiness directives, what were the compliance
13 times given to the operators? How long can they go
14 before they have to comply with those?

15 WITNESS HARTONAS: The compliance time for
16 the scavenge pump, I believe, is 90 days.

17 MR. SWAIM: That's the newest one for the
18 ground, the electrical connector?

19 WITNESS HARTONAS: Yes. The compliance time,
20 or the common period for the proposed AD, the MPRM, is
21 90 days, and it provides for one year of compliance
22 time.

23 MR. SWAIM: So, a year-and-a-quarter,
24 essentially. Okay. Thank you.

25 I have no further questions at this time.

1 CHAIRMAN HALL: Do any of the Technical Panel
2 have any questions?

3 MR. DICKINSON: I have one short question for
4 Mr. Chris Hartonas.

5 You mentioned at the start of the
6 conversation about the 200 microjewels as an industry
7 standard, can you go over how the industry standard is
8 established?

9 WITNESS HARTONAS: It is a long history about
10 the establishing the energy level that would cause an
11 ignition in the fuel tank. There is probably testing
12 in volumes of the study. My knowledge simply has to do
13 with the energy level. I'm not a fuel expert. I
14 support the electrical systems in the equipment area.

15 Knowing that there is 200 millijewel energy
16 level can cause an ignition in the tank is enough for
17 me.

18 CHAIRMAN HALL: Any other questions from the
19 Technical Panel?

20 (No response)

21 CHAIRMAN HALL: No. We have one last one.

22 MR. HAUETER: Mr. Taylor, previously this
23 year there have been two electrical wiring fires
24 outside the tank on 747. Does that give you concerns
25 about the integrity of the jewel location system.

1 MR. TAYLOR: You're talking about electrical
2 wiring fires of wiring not associated with the fuel
3 quantity system?

4 MR. HAUETER: The fuel quantity system may
5 run in those same bundles, yes, sir.

6 MR. TAYLOR: I don't really think I have a
7 comment at this point.

8 MR. HULM: I would like to address that,
9 since it's related to the wiring in the airplane and
10 the wire fires that have been seen, the --

11 CHAIRMAN HALL: Well, I think that Mr. Taylor
12 owes us either an answer, or he is not going to answer,
13 one of the two. That's fine either way with the
14 Chairman.

15 MR. TAYLOR: I think Boeing probably would
16 have a much better answer.

17 CHAIRMAN HALL: Well, you make the product,
18 and I think the question is, are you concerned about a
19 fire on wire bundles that run into your product that
20 you just make this long presentation on?

21 Is that the question?

22 MR. HAUETER: Yes, sir, it is.

23 MR. TAYLOR: I would say, the way the product
24 is designed with the components we have built into it,
25 that, no, we're not concerned. I don't think that

1 wiring bundle fires are going to put 1,500 volts into a
2 fuel quantity system.

3 CHAIRMAN HALL: Thank you.

4 MR. HULM: I kind of echo that, too. And in
5 a little more detail, again, the components within the
6 tank are rated up to 1,500 volts AC, and they test up
7 to 1,500 volts AC. Any 115 volt source that comes from
8 the airplane is not going to do anything inside the
9 tank, and once you do get damage like, if you get 115
10 volts AC on that wiring, the indicator and the flight
11 deck is going to fail, and you're going to notice it.
12 The flight crew is going to notice it; the maintenance
13 crew is going to notice it, and they're going to fix
14 the system.

15 In addition to wiring that runs, the majority
16 of the wiring runs from the flight engineer's panel
17 down to the center tank itself is a high temperature
18 teflon installation. The wire itself is rated for
19 1,000 volts AC continuous operation at that
20 temperature, and the bundle for the FQIS system itself
21 is protected with a varnished nylon sleeve to protect
22 against abrasion. The nylon sleeve won't do you any
23 good in a fire event, but it does prevent abrasion to
24 the adjacent wires.

25 One thing we did notice from the accident

1 investigation was that the wiring over the center tank,
2 especially where there was the fire itself where a
3 majority or all the wires that were in that particular
4 channel where there were wire bundles routing, all that
5 wiring was basically destroyed except for the FQIS
6 wiring, which was pretty much intact.

7 SO, that wire is some pretty tough stuff in
8 consideration of wire fires and arcing and everything.
9 But the overall consideration, if you get 115 volts on
10 that, that wiring going to the tank - is that going to
11 cause an ignition? - No, it won't. The components will
12 withstand that; the wiring will withstand that.

13 DR. LOEB: Barring no other latent failures.

14 MR. HAUETER: I'd like to follow up on that.
15 How do we know it won't? You say it won't. How do we
16 know that?

17 MR. HULM: That's what we test in the lab.
18 We took an entire center tank set up, probes, wiring
19 and everything. We put that in a chamber that had fuel
20 vapors in it, and it was kind of by accident, but
21 that's the way the test was conducted.

22 Then we subjected that to up to 3,300 volts
23 before we started seeing arcing and any of the
24 insulated components.

25 DR. LOEB: And below that, you were unable to

1 see any evidence of arcing under those conditions you
2 were doing?

3 MR. HULM: Correct.

4 DR. LOEB: That doesn't mean that slight
5 variations in that, you may not, I mean, we don't know
6 what we don't know. We only know what we test for; is
7 that correct?

8 MR. HULM: Correct.

9 MR. TAYLOR: If I could add to that. On that
10 particular testing, you're not only just not seeing any
11 arcing, but you're majoring in current flow and run it
12 up to in excess of 3,000 volts and zero current flow,
13 there is no arc, and it was very, very clear, when you
14 really muscled this up and pushed it to the point where
15 it was going arc, just from the indications, the arc
16 was very evident and you would see the voltage drop,
17 current go up.

18 DR. LOEB: Thank you.

19 CHAIRMAN HALL: Okay. Other questions?

20 DR. BIRKY: Mr. Chairman, may I follow that
21 answer up with a question, sir?

22 CHAIRMAN HALL: Certainly, Dr. Birky, go
23 ahead.

24 DR. BIRKY: Mr. Hulm, are you suggesting that
25 in a fire outside the tank, that teflon will withstand

1 that fire and maintain the insulation integrity of the
2 wire?

3 MR. HULM: I can't make that guarantee, you
4 know, in all cases. I'm just saying, that was one
5 particular instance where there was a fire, and that
6 teflon wiring did survive. I am sure there are other
7 instances where the fire can be intense enough where it
8 will destroy that wiring.

9 DR. BIRKY: Okay. Thank you.

10 CHAIRMAN HALL: No other questions from the
11 Technical Panel?

12 Mr. Sweedler.

13 MR. SWEEDLER: Yes, Mr. Chairman.

14 I have one question for Mr. Thomas: We had
15 quite a bit of discussion about what was found in this
16 special service bulletin on the 52 airplanes that have
17 already been inspected, but early in your testimony you
18 describe a system where the operators of your airplanes
19 can report problems back to you.

20 In those reports that come back to you, can
21 you tell us about any particular problems that have
22 been reported by the operators that cover center fuel
23 tanks, temperatures in the tanks, possible ignition
24 sources, anything of that nature that may have been
25 reported by the operators of the 747s?

1 WITNESS THOMAS: Let me think about that.
2 The short answer is, no. I know of no issues that
3 would be considered a safety issue, other than the
4 discussion we had already about the connectors outside
5 the fuel tank themselves on the center wing pumps.

6 MR. SWEEDLER: Well, other than just the
7 safety issue, are there any particular problems with
8 the equipment in the tank?

9 WITNESS THOMAS: Not that I'm aware of.

10 MR. SWEEDLER: Okay. Thank you, sir.

11 CHAIRMAN HALL: Dr. Ellingstad.

12 MR. ELLINGSTAD: Both Mr. Cheney and Mr.
13 Thomas used the term "explosion-proof," and I'd just
14 like to get a clarification of what we are implying
15 here.

16 Mr. Cheney, do I understand correctly that
17 your use of this term was restricted to eliminating the
18 threat of ignition of auto ignition from elevated
19 temperatures on internal components in the tank?

20 WITNESS CHENEY: That's how it's intended in
21 the advisory circular that I was discussing; that's
22 correct.

23 MR. ELLINGSTAD: Mr. Thomas, you used this
24 same term in connection with the performance of boost
25 pumps, and seem to imply something a bit more general

1 than that. What systems are explosion-proof from
2 Boeing's point of view?

3 WITNESS THOMAS: We use the term, "explosion-
4 proof" in two senses. One, if you have a component
5 that is in a sealed compartment, if you will, and the
6 compartment can tolerate an explosion with the surface
7 temperatures reaching 390 degrees, or the appropriate
8 temperature. That is considered explosion-proof.

9 We also look at the situation where we have a
10 vented container, which is really the pump and motor
11 housing that I described earlier, where not simply
12 having a design with a temperature. The surface
13 temperatures do not go over 390. That is part of the
14 proof that it's explosion-proof.

15 The other part is that the venting of that
16 chamber is also explosion-proof, in other words, the
17 flame cannot propagate out of the chamber. So, there
18 is a combination of those two tests that satisfy us
19 that the pump is explosion-proof.

20 MR. ELLINGSTAD: Just to be clear, neither of
21 you were using that language to describe a center wing
22 tank that was subjected to an explosion?

23 WITNESS THOMAS: No .

24 MR. ELLINGSTAD: Mr. Thomas, with respect to
25 your temperature limits - and again the Boeing standard

1 of 50 degrees less than the auto ignition temperature -
2 you did say that this applied to the inside of the
3 tank?

4 WITNESS THOMAS: Correct.

5 MR. ELLINGSTAD: Under what conditions is
6 that assessed, specifically, with respect to adjacent
7 kinds of equipment that might assume different
8 temperatures, air cycle machines, for example?

9 WITNESS THOMAS: Our design is such that we
10 certify the design to ensure that we do not exceed 390
11 degrees anywhere inside the fuel tank. We look at
12 ducting running down the leading edge, for instance,
13 which we deliberately control to be normally below the
14 390 degrees. On extremely hot days, it may go up as
15 high as 450. If there is a failure in the system where
16 it could go higher than 450 in the leading edge, then
17 we shut down the system.

18 We look at duct impingement, we have overheat
19 detectors in the leading edge to protect the system; in
20 other words, if I have a duct failure where I could be
21 impinging hot air onto the center tank, in a local
22 area, we will detect it and shut down the system
23 supplying that hot air.

24 The other area in the airplane where you have
25 obviously high temperatures, or in the fire zone of the

1 engines themselves where they are quite a long way away
2 from the fuel tanks.

3 MR. ELLINGSTAD: Okay, thank you.

4 Finally, Mr. Hulm, you have talked about the
5 measurements that are taken and the protections with
6 respect to electrical components. Are you exclusively
7 concerned with arcing as an ignition source with
8 respect to this standard in your tests?

9 MR. HULM: This particular standard is kind
10 of basic to most aerospace components, and it has to
11 deal with the insulating capability of the parts
12 themselves in being able to last in the environment,
13 the entire temperature pressure in life of the
14 aircraft.

15 So, it's not strictly related to just arcing
16 within fuel tanks. I think if you look at a lot of
17 electrical components on aerospace equipment airplanes,
18 you're going to find this requirement applied almost
19 universally. So, it's not just specifically related to
20 arcing, but that is the event you're looking for when
21 you conduct these tests.

22 MR. ELLINGSTAD: Okay, thank you.

23 CHAIRMAN HALL: Dr. Loeb.

24 DR. LOEB: Mr. Hulm, I just want to revisit
25 one more time this issue of your contention that there

1 are no ignition sources within the tank. You have said
2 that; is that correct?

3 MR. HULM: That's correct.

4 DR. LOEB: Does that not assume that there
5 are no failure of any systems for that to be the case?

6 MR. HULM: That assumes under the conditions
7 that we know about as far as different failures that
8 could occur, that there are no ignition sources in the
9 tank.

10 DR. LOEB: Are you suggesting that there is
11 no combination of failures that could occur that could
12 put an ignition source in that tank?

13 MR. HULM: No. I think we can imagine any
14 combination of failures that can put an ignition source
15 in the tank. What we have to look at in designing the
16 equipment is, what is most likely, what is likely to
17 occur? So, that's the way we do it.

18 DR. LOEB: No, I understand that, but I think
19 it's important to clarify and not leave the impression
20 that there is no possibility that there could be
21 multiple failures that lead to ignition source.

22 MR. HULM: I concur, sir.

23 DR. LOEB: And Mr. Thomas, I wanted to
24 follow-up just for a second on Dr. Ellingstad's
25 questions regarding the auto ignition temperature in

1 the systems that are there to protect against.

2 If you had a duct failure in the plenum above
3 the tank and you were getting air temperatures above
4 what you may normally expect out of the bleed (sic) air
5 out of the engines, is there any system, any
6 temperature-measuring device within the tank, or in
7 that area that would protect against that kind of
8 system where you were heating the ullage from the top
9 with the air from the engines?

10 WITNESS THOMAS: There are several protection
11 features there. The engine controls this in itself.
12 It is regulating the air coming out of the engine up
13 into the strut. We have cooling systems on board the
14 engines, and they are in effect monitoring and
15 regulating the temperature of the air coming out of the
16 engine.

17 If that system sees a failure, it is capable
18 of shutting down the valves that control the air coming
19 out of the engine. If the failure occurs going down to
20 the leading edge of the wing, we have overheat
21 detection systems in the leading edge of the wing.

22 so, we have two mechanisms. We have an
23 automatic control system that controls and modulates
24 the air temperature going from the engines down the
25 leading edge, and then we have overheat detectors in

1 the leading edge.

2 Mr. Cheney referred to the wheel wells. We
3 have fire detectors or overheat detectors in the wheel
4 wells, where there is overheat in the wheel well that
5 could be potential problem to the rear spar, and then
6 the crew gets a warning, and they're instructed to
7 lower the landing gear, which in effect sweeps any
8 combustibles out of the landing gear bay itself and
9 puts the fire out.

10 DR. LOEB: Is the air in the ducts above the
11 tank with no failures in the system, is it other than,
12 say, a failure in the duct, is it hot enough to heat
13 the tank to auto ignition?

14 WITNESS THOMAS: There are no ducts above the
15 tank. They're on the leading edge on the forward of
16 the tank.

17 DR. LOEB: Right; yes. But they can get to
18 that area of the tank. Now, is that air hot --

19 WITNESS THOMAS: No. That air is normally
20 running at 350 out there, but not enough. By the time
21 you cool that air in the mixing process from the leak
22 to the front spar, plus the temperature that it will be
23 of heat that will be transmitted away from in the spar
24 itself, we do not see there is any way that we can get
25 to 390 degrees inside the tank.

1 DR. LOEB: Okay. Thanks .

2 CHAIRMAN HALL: I just have a few questions
3 so we can finish up on time, and this being the fuel
4 design, tank design philosophy and certification panel,
5 I understand that the basic philosophy is to engineer
6 out the ignition sources. Its been done in the past,
7 and I appreciate what's been mentioned by FAA and
8 Boeing to look at the issue that's been raised about
9 the explosive vapors.

10 But just to stay on the engineering, not the
11 ignition sources for a minute: That, I guess, assumes
12 that there are some ignition sources that could
13 possible get in the tank, and you have identified
14 those, or not. I guess we couldn't put a number on
15 that, either Mr. Thomas or Mr. Hulm.

16 I'm referring now, I guess, to what the
17 industry response to the FAA was in the request for
18 comment, Title, Fuel Tank Ignition Prevention Measures.
19 I don't' know if that's an exhibit to this?

20 MR. SWAIM: I believe, sir, we will be
21 referring to that in the flammability reduction.

22 CHAIRMAN HALL: All right. So, therefore,
23 the industry plans to voluntarily undertake either a
24 sampling of high time aircraft or major fuel tank
25 inspection programs to (1) verify the integrity of

1 wiring and grounding straps; (2) the conditions of fuel
2 pumps, fuel lines and fittings; and (3) the electrical
3 bondings on all equipment.

4 so, would failures or malfunctions of those
5 be possible ignition sources in the tank, or why is
6 that inspection program being undertaken?

7 MR. HULM: That is the purpose behind the
8 inspection program is to look to see if there has been
9 any degradation in the bonds or grounds that have
10 occurred.

11 CHAIRMAN HALL: And you've got to open the
12 tank to do that?

13 MR. HULM: Correct.

14 CHAIRMAN HALL: And you say you're concerned
15 about how often you open the tank. Do you have
16 guidelines on how often you open the tank?

17 Boeing?

18 WITNESS CHENEY: I think that was a comment I
19 made. Currently, there is no requirement to --

20 CHAIRMAN HALL: Well, let me ask Boeing: Do
21 you have a concern about opening the tank?

22 MR. HULM: I think we definitely do.

23 CHAIRMAN HALL: Do you have a time, do you
24 have how often it should be opened and inspected?

25 MR. HULM: We don't provide any

1 recommendation along that respect.

2 CHAIRMAN HALL: Well, what I'm trying to
3 understand, what I'm trying to grasp is, we engineer,
4 under the concept we've had in the past, we engineer
5 out the ignition sources. We have identified possible
6 areas of electrical components leading into the tank
7 that might be possible ignition sources, and I think I
8 understand that you try, even if there are failure
9 modes of those, to be sure there is not enough energy
10 to ignite the tank.

11 But, then, that's never inspected, except
12 when? How often is that inspected and looked at?
13 Because it would seem to me, unless you inspected those
14 routinely, then the basic premise of which your
15 philosophy is based on needs a little improvement.

16 MR. HULM: The way the systems are designed,
17 is that we don't have any regular maintenance. We at
18 Boeing don't have any regular maintenance that requires
19 tank entry. It's all on condition if there is a
20 failure of a component within the tank, then we do
21 specify how to correct it and repair it.

22 WITNESS THOMAS: In addition to that, because
23 of the structural inspections I referred to earlier
24 where we needed to go and look at the tanks to see how
25 well the structure is doing with time, we do what we

1 call zonal inspections are called out where, if you're
2 in a tank area looking at the structure, you also look
3 at the condition of the systems in that general area.

4 There are other checks that we do, things
5 like the check valves that I referred to on the boost
6 pumps, some of the ellens (sic) will remove those check
7 valves, run through a vent and restore them into the
8 airplane, and we do functional tests on the airplane to
9 look for those kinds of failures.

10 so, it's a combination of periodic tank
11 visits really as a force by the structural inspection
12 requirement, but also allows us a chance to look at the
13 fuel system. We don't go into the fuel system -- go
14 into the tanks specifically to look at a fuel system on
15 a regular - this inspection program --

16 CHAIRMAN HALL: Could I ask Ms. Rodrigues,
17 does the Air Force have any different requirements in
18 what was described for your center fuel tank
19 inspections?

20 MS . RODRIGUEZ: We have depot maintenance
21 inspection. Again, it depends really on the program on
22 the airplane. Most are made in, like --

23 CHAIRMAN HALL: Well, give us the 747.

24 MS . RODRIGUEZ: -- five years. Five years,
25 and at that time, we do an extensive functional check

1 of the fuel system; otherwise, it is only on either you
2 have a leak or a component fails, and we don't have a
3 limitation of how many times you can enter the tank
4 either; as much as is needed to repair.

5 CHAIRMAN HALL: Well, I would hope that the
6 FAA would look into that matter because we need to
7 clarify for the traveling public what inspection we're
8 doing and what the reasonable time frame is we're going
9 to do it in, and you say, it's already been
10 accomplished on Air Force I. I'm sure most citizens
11 would want it accomplished on the 747 thereon, as well.

12 Did any of the members of the Panel have any
13 other comments that they would like to make or
14 contribute? I appreciate all of you all. I have read
15 your backgrounds and biographies. All of you all have
16 impressive credentials in your field.

17 Mr. Cheney and Mr. Thomas, I appreciate your
18 service to the Government, and if any of you all feel
19 that there is anything that we have missed or any
20 personal contribution you would like to make or
21 comment, please take the time to do so.

22 Mr. Taylor?

23 MR. TAYLOR: No, thank you. No comments.

24 CHAIRMAN HALL: Mr. R. Thomas?

25 MR. R. THOMAS: Not at this time, Mr.

1 Chairman.

2 CHAIRMAN HALL: Mr. Cheney?

3 WITNESS CHENEY: No, Mr. Chairman.

4 CHAIRMAN HALL: Mr. Thomas?

5 WITNESS THOMAS: I would just like to
6 reiterate what I said in terms of this activity we're
7 undertaking today where we're addressing fuel
8 flammability, is a major philosophical relook at how we
9 do it. It's very important. The Boeing Company is
10 very committed to pursue this. The FAA has proposed
11 the Eric process as a way of doing "a fast track"
12 activity, to look at all these suggestions.

13 We totally support that activity, and really
14 want to press forward.

15 CHAIRMAN HALL: Well, Boeing is one of the
16 largest companies in our country, and everyone is
17 familiar with that name like they are "Coca-Cola."
18 Well, I'd better not say any other names.

19 I appreciate the questions from the Boeing
20 table because all I wanted to get out was what you were
21 doing, since TWA, and I knew you were doing a number of
22 things, but I think it's important in this public
23 hearing on this accident that the American people know
24 what the manufacturer of the plane is doing.

25 None of are saying we know what caused the

1 accident. We don't have the ignition source for this
2 accident, but what are we doing as a Government, as an
3 industry, as an airline, to be sure that until we know,
4 that we're doing everything that you or I would want
5 done.

6 Mr. Hulm?

7 MR. HULM: I guess I'd also like to clarify
8 some of my comments to make sure. I agree with you,
9 the fact that we don't know what caused the explosion
10 in the center tank at TWA-800, and we're not closed to
11 anything at this point in time. We are keeping an open
12 mind, and there is nothing that we have ruled out as
13 any sort of possibility, and so if something does come
14 up and the work with the NTSB is done, and working with
15 the FAA, I think the cooperation there has been pretty
16 good, and there has been a lot of good work put in; but
17 there is still one heck-of-a-lot-of-work to do.

18 so, we're not closed off from that.

19 CHAIRMAN HALL: Thank you very much.

20 MR. HULM: Thank you, sir.

21 CHAIRMAN HALL: Ms. Rodriguez?

22 MS . RODRIGUEZ: No comment.

23 CHAIRMAN HALL: And I can't see that far, so
24 you will have to help me with the name again, sir. I
25 apologize. I don't have it in front of me.

1 WITNESS HINDERBERGER: Ron Hinderberger.

2 CHAIRMAN HALL: Yes, Mr. Hinderberger.

3 WITNESS HINDERBERGER: Mr. Chairman, I guess
4 I would just like to add that as an industry, there is
5 a genuine concern right from the beginning of this
6 accident, and our participation at Douglas Aircraft at
7 the time of the accident, since becoming part of the
8 Boeing Company, of course; but right from the beginning
9 of the accident, the industry as a whole, speaking on
10 behalf of Douglas Aircraft, became very concerned about
11 this accident and have been very active in various
12 committees to try to uncover as many possibilities as
13 we can to get to the root case, and what can we
14 eventually do to make air travel even safer than it is
15 today.

16 CHAIRMAN HALL: Well, you have been an
17 excellent Panel, and I appreciate very much your
18 presentation.

19 You are excused, and we will stand in recess
20 until 2 o'clock, at which time we will return for the
21 Flammability Panel.

22 (Whereupon, at 12:53 p.m., the hearing in the
23 above-captioned matter was adjourned for luncheon
24 recess, to reconvene at 2:00 p.m., this same day.)

25

AFTERNOON SESSION

[Time Noted: 2:00 p.m.]

CHAIRMAN HALL: We will reconvene this session, this hearing, the National Transportation Safety Board, and move to the next agenda item, which is the Flammability Panel, and I would ask Mr. Dickinson to please introduce the Panel and swear them in.

MR. DICKINSON: Would the Panel members please stand up.

(Panel Members Stood up.)

MR. DICKINSON: And would the questioners please stand up to include Dr. Merritt Birky, Dr. Dan Bower and Dennis Crider.

Whereupon,

DR. JOSEPH SHEPHERD, DR. JOHN SAGEBIEL, DR. PAUL THIBAUT, DR. MEL BAER, DR. KEES VAN WIN GERDEN, and JIM WOODROW

were called as witnesses by and on behalf of the NTSB and, having been first duly sworn, were examined and testified on their collective oaths as follows:

MR. DICKINSON: Thank you. Please be seated.

This afternoon's Panel, Mr. Chairman, will

1 consist of presentations by Dr. Birky, Dr. Bower and
2 various Panel members.

3 Questioners will also be questioned by Mr.
4 Dennis Crider.

5 Dr. Daniel Bower has been with the Safety
6 Board for two years as an Aerospace Engineer. He served
7 as an Performance Group Chairman on several major
8 accidents, including the 1996 Value Jet accident in
9 Florida.

10 Prior experience includes Research
11 Engineering at the Calspan University at Buffalo
12 Research Center where he performed experimental
13 research in hypersonic aerodynamics and heat transfer.

14 He also worked as an aerospace engineer at
15 the Air Force Wright Aeronautical Laboratories. He has
16 a B. S. in Aerospace Engineering from State University
17 of New York in Buffalo, and his Ph.D. is in Aerospace
18 Engineering, specializing in compressible fluid flow
19 and boundary layer stability.

20 Dr. Merritt Birky has been with the Board for
21 14 years. He is a National Resource Specialist in the
22 Office of Research and Engineering. He has
23 participated in the investigation of some of the
24 nation's major aviation accidents, including the
25 downing of PanAm Flight 103, the Space Shuttle

1 Challenger, the U. S. Air Force Titan, and the Value
2 Jet investigation.

3 He has participated in the investigation of
4 major railroad, pipeline and marine accidents also,
5 including the Exxon Valdez in Alaska.

6 Prior to joining the Safety Board, he worked
7 for more than 20 years at the National Bureau of
8 Standards, then served as Director of Research at the
9 Foundation for Fire Safety.

10 CHAIRMAN HALL: Mr. Dickinson, do you know if
11 Dr. Birky's biography is on the Internet?

12 MR. DICKINSON: Yes, sir. All the
13 biographies have been entered in on the Internet.

14 CHAIRMAN HALL: The Chairman was disappointed
15 when he noticed that Dr. Birky's biography was not on
16 the Internet this morning. I want to be sure it's on
17 the Internet before we proceed.

18 Dr. Ellingstad, has that been done?

19 MR. ELLINGSTAD: Yes, sir.

20 CHAIRMAN HALL: Very well.

21 Well, we may proceed then.

22 MR. DICKINSON: Getting back to Dr. Birky, he
23 has a Bachelor's Degree from Goshen College, and a
24 Doctorate from the University of Virginia, and he has
25 done some work at NIH Graduate School in Toxicology.

1 Dr. Joseph Shepherd is an Associate Professor
2 of Aerospace.

3 CHAIRMAN HALL: If your names are there,
4 please hold your hand up as you are introduced. I
5 would appreciate it.

6 (Dr. Shepherd raised his hand)

7 MR. DICKINSON: Thank you, Dr. Shepherd.

8 California Institute of Technology; he heads
9 the Explosion Dynamics Laboratory at Cal Tech in
10 Pasadena; directs experimental and computational
11 studies on combustion, explosion and shock waves;
12 specializes in studies related to safety and explosion
13 hazards in transportation systems; has 17 years
14 experience in experiments, analysis and computation of
15 explosion phenomena.

16 Dr. Shepherd has been a Consultant, an
17 investigator on numerous projects for the DOE, U. S.
18 Nuclear Regulatory Commission, NASA and various
19 national laboratories. He has a B. S. in Physics from
20 the University of South Florida, and a Ph.D. in Applied
21 Science, California Institute of Technology.

22 Next, we have Dr. Sagebiel.

23 (Dr. John Sagebiel raised his hand)

24 MR. DICKINSON: Thank you.

25 Assistant Research Professor, Energy and

1 Environmental Engineering Center, Desert Research
2 Institute, University of Nevada. He has had five years
3 with DRI, and it's centered on sampling and measuring
4 of hydrocarbon species in ambient air and source
5 samples.

6 He has worked on the development of numerous
7 analytical methods, and worked on performance
8 evaluations of air sampling systems.

9 He has a B. S. in Environmental Toxicology.

10 Dr. Melvin Baer.

11 (Dr. Melvin Baer raised his hand)

12 MR. DICKINSON: Thank you. Is a Senior
13 Scientist with Sandia National Laboratories; he was 21
14 years with Sandia at the Engineering Sandia National
15 Laboratories in Albuquerque, New Mexico; promoted to
16 Distinguished Member of the Technical Staff in 1989;
17 has conducted extensive scientific research in the
18 field of Energetic Materials and Explosives; served as
19 a participant on numerous hazard evaluation programs
20 for the Department of Energy and the Department of
21 Defense.

22 He has a B. S., M. S., and Ph.D. in
23 Mechanical Engineering from the Colorado State
24 University.

25 Next, we have Dr. Paul Thibault.

1 (Dr. Paul Thibault raised his hand)

2 MR. DICKINSON: From Combustion Dynamics
3 Limited, he founded that organization, which provides
4 scientific software and analysis services in the areas
5 of explosions, shock waves, supersonic combustion and
6 propulsion, CDL; has developed strong capabilities in
7 computational fluid dynamics, and computational solid
8 mechanics .

9 It operates a laboratory facility for
10 combustion experiments and a large-scale heated
11 detonation tube facility.

12 He previously worked at the Pat Bay Ocean
13 Science Institute at the Defense Research establishment
14 in Suffield, and worked on detonations, flames and
15 gaseous explosions at McGill University, from which he
16 got his Bachelor Degree in Mechanical Engineering in
17 1972, and his Ph.D. in 1978.

18 Following him, we have Dr. Kees Van Win
19 Gerden.

20 (Dr. Kees Van Win Gerden raised his hand)

21 MR. DICKINSON: Thank you, sir.

22 He's the Manager of the Department of Process
23 and Safety in Christian Michelson Research, otherwise
24 know as Sam R. He is employed at Sam R, he has been
25 employed since 1991. Dr. Van Win Gerden is

1 responsible for research into gas and dust explosions.
2 He has directed a number of large research programs,
3 such as the gas safety program sponsored by several gas
4 and oil companies and Government bodies, and resulting
5 in three new versions of the facts code. It's a three-
6 dimensional exposure simulator.

7 Dr. Van Win Gerden is author and co-author of
8 more than 50 articles on gas and dust explosions. His
9 education includes a B. S., and M. S. and a Ph.D. in
10 Applied Physics from the University of Bergen in
11 Norway.

12 And last, but not least, we have Mr. Jim
13 Woodrow, who is a Laboratory Manager at the University
14 Center for Environmental Sciences and Engineering at
15 the University of Nevada at Reno. He has worked for
16 Dow Chemical Company, Shell Development Company, and
17 has been a teaching assistant at the University of
18 California; is currently the Laboratory Manager for the
19 University Center for Environmental Sciences and
20 Engineering, University of Nevada at Reno.

21 And his education includes a B. A. and an M.
22 s. in Chemistry from San Jose State University.

23 With that, I will turn the microphone over to
24 Dr. Merritt Birky.

25 Are you going to be first?

1 Presentation By

2 DR. MERRITT BIRKY

3

4 MR. BIRKY: Good afternoon, Mr. Chairman,
5 Members of the Board of Inquiry, Ladies and Gentlemen.

6 This is a Flammability Panel. What I would
7 like to do in terms of sequence to give you a bit of a
8 road map, is that I will give a short presentation,
9 followed by Dr. Bower, then followed by Dr. Shepherd,
10 and then very short with Dr. Sagebiel and Mr. Woodrow,
11 and then will go back to Dr. Shepherd, and then go into
12 the modeling with Dr. Thibault and Dr. Mel Baer.

13 I would like to start with a very short
14 tutorial on flammability, and I think we got into a lot
15 of that this morning. Some of it will be a bit
16 redundant, but hopefully, some of it will stick as a
17 result of that. So, what we're going to do, the
18 Flammability Panel will go into laboratory explosion
19 results, flight test data, vapor chemistry, quarter
20 scale and modeling.

21 For the tutorial, I have a few cartoons, I
22 think, that will demonstrate the relationship between
23 ignition sources and flammability. And that was a big
24 issue of discussion this morning.

25 For a fire or explosion to occur, we must

1 have three elements, that is, we must have oxygen, fuel
2 and an ignition source. If you want to interrupt that
3 process, that is, prevent an explosion or fire, one has
4 to remove one of those three elements: Ignition
5 source, which is the philosophy which has been used on
6 aircraft, but the other way to do that is to eliminate
7 the fuel.

8 It's very difficult to eliminate the oxygen
9 unless you do some type of inner process.

10 Solids and liquids do not burn. They must
11 first be converted to vapor, converted into the vapor
12 phase. If you're talking about Jet A in an aircraft
13 tank, then you generally must have some heat to do
14 that.

15 Jet A is a very complex fuel, and made up of
16 many different compounds. The vapors that we're
17 talking about for an explosion in this case were
18 generated when the bottom of the tank containing about
19 50 gallons of fuel, and it was heated up as a result of
20 the air-conditioning packs used to condition the cabin
21 of the aircraft.

22 These vapors are very much like that that
23 comes off of a pot of water on the stove when it's
24 heated, although in this case, the vapors are
25 flammable, that is, they will burn, and the water

1 vapors are not flammable.

2 This graph is used to illustrate the vapors
3 in the air in a tank; the red line at the bottom is a
4 liquid fuel. In this case, we're talking about Jet-A.
5 The red circles are the hydrocarbon molecules, and the
6 blue represent the oxygen in the tank.

7 This slide represents sort of a cold
8 situation in which you have very few molecules of the
9 hydrocarbon in the vapor phase, so you're not likely to
10 have a fire or an explosion in that case. If we put
11 heat under the tank, then we increase the number of
12 fuel molecules for that combustion process to occur.

13 Now, I tried to use a little bit different
14 size circles for the fuel hydrocarbon molecules to
15 represent different compounds, if you will, since it's
16 a very complex mixture.

17 As you heat up the fuel, the number of those
18 fuel molecules, of course, increase into the ullage
19 space, or the vapor space that we have above the liquid
20 fuel, and if you hear the word "ullage" in my
21 presentation and others, we're referring to the space
22 above the liquid inside the tank, the air space,
23 basically.

24 Now, if I take a cup of Jet-A or any
25 combustible liquid and slowly heat it up, and have an

1 ignition source at the top of that, I will come to a
2 point which the vapors will support combustion, and
3 that point in which that happens is called the flash
4 point that we've talked about before.

5 There is a standard ASTM method that's used
6 for that measurement, and fuels are frequently
7 classified according to that test method, and there is
8 a thermometer indicated in that cartoon there, right
9 there (indicating) .

10 Now, I can do a series of experiments with
11 that particular apparatus, and this is a plot that
12 shows the temperature on the horizontal axis and the
13 altitude on the vertical axis. I direct your attention
14 over to the right-hand side of that screen, and Jet-A,
15 for example, has a flash point roughly, usually above
16 100 degrees Fahrenheit, as we heard this morning, and
17 that at sea level, which is zero altitude, is down
18 here.

19 If I do that same measurement at altitudes,
20 say, at the top of Pike's Peak at about 14,000 feet, I
21 will get a flash point that will be at a lower
22 temperature, a little bit than that at sea level. If I
23 continued to increase the temperature in that apparatus
24 that had previously had shown, I will reach a level at
25 which the fire no longer continues to burn, and that is

1 the temperature here indicated at that point, about 190
2 degrees, something like that.

3 Those two lines then, if I do that
4 temperature at different altitudes, those two lines
5 represent the lower flammability limit, as indicated,
6 and the upper flammability limit.

7 The Jet-A that we had from a net tank on TWA-
8 800 had a flash point of about 113 degrees Fahrenheit.
9 For comparison purposes, I put on there the flash
10 points of gasoline, since most people are more familiar
11 with gasoline in their automobiles, and by the way,
12 this slide basically comes from the reference
13 literature and represents typical fuels.

14 Now, as you see in that graph, the flash
15 point, the lower flammability limit of gasoline at sea
16 level is approximately minus 40 degrees Fahrenheit, and
17 for those in the audience that have diesel cars, this
18 graph explains why diesel fuel cars are harder to start
19 in the wintertime than those in gasoline cars, for
20 Diesel has a flash point very similar to Jet-A. It's a
21 kerosene, as Jet-A is, and if you remember what I said
22 earlier, for fuel to burn, it must be in the vapor
23 state.

24 In the wintertime, when the fuels are very
25 cold, the diesel fuel has very few molecules in the

1 vapor phase, so it makes it harder starting an
2 automobile in the wintertime on diesel fuel.

3 Now, if I put this Jet-A inside a closed
4 container and heat it up, and then put a spark inside,
5 the container, will, of course, explode or burst, and
6 that's the result of the generation of pressure from
7 the heat and from the gabushen (sic) process. This
8 explosion can be extremely powerful.

9 Now, having talked about the fuel side of the
10 equation of the triangle, let me go on to the ignition
11 side, if I might.

12 The amount of energy that is required to
13 ignite hydrocarbon vapors is strongly dependent on the
14 temperature of the liquid. The scientific literature
15 states that the minimum energy for hydrocarbon vapor
16 ignition is roughly one-quarter of a millijewel, and we
17 heard a lot of discussion about this this morning.

18 The question was raised, how much is a
19 quarter-of-a-millijewel? Well, we can illustrate this
20 -- sorry - before I go on and do that illustration,
21 let me point out two things: There are two
22 temperatures I talked about this morning that I just
23 put into this presentation, the flash point and the
24 auto ignition point, and they are quite different. As
25 you can see, the flash point of Jet-A is about 100, and

1 the auto ignition temperature of Jet-A is about 450
2 degrees.

3 Let's now go back to the ignition issue. I
4 chose to represent the quarter-of-a-millijewel, as I
5 stated this morning, by holding a dime about a half-an-
6 inch above the table top, and that dime held there has
7 roughly the potential energy of a quarter-of-a-
8 millijewel, and if you drop that dime, that energy,
9 potential energy, will be converted to kinetic energy
10 and will strike that table with that appropriate
11 energy.

12 As you can see, this is a very small amount
13 of energy, so small, in fact, that is this is the
14 energy that ignited the tank in Flight 800, there would
15 be no signature witness mark to see in the recovered
16 hardware. Is this the amount of energy is actually
17 took to do that in this particular accident?

18 Well, we don't know that, but if the energy
19 is higher, that is, if the fuel is considerably colder,
20 it may take up to 10-to-100 jewels. We are going to
21 hear more about that; and the question then is, how
22 much is that?

23 Well, if I am talking about 10-to-100 jewels,
24 then I want to illustrate it with my dime. I would
25 have to put it about 5-to-6 miles in the air to

1 represent that type of energy. Obviously, we won't get
2 it when it hits, but that's basically if you want to
3 run a tube and valuate that distance, you could
4 probably do it.

5 When we first realized an explosion at center
6 wing tank on this aircraft, it was a primary or
7 initiating vent that resulted in loss of the aircraft.
8 The first obvious question was: Why were the vapors
9 above the lower flange limit; and second, what was the
10 ignition source for the vapors?

11 The work that we're going to be reviewing has
12 the ultimate goal, the identification of the ignition
13 source. Part of this inquiry is knowing how much
14 energy is required to ignite the vapors, and within the
15 tank there are two general classifications in that tank
16 that we could put in that is a higher energy system,
17 that is, the fuel pumps we talked about, and a lower
18 energy system, the gauging system.

19 If a large amount of energy is required, then
20 we're talking about other than the gauging system.

21 I would like to show a picture on the
22 visualizer right not that illustrates the gauging
23 system in the tank. There are tubes. Everyone, I
24 think, is now pretty familiar with the gauging system
25 in the tank, and the pumps, of course, in the back

1 spar.

2 Of course, there are other possible ignition
3 sources that we won't address here, but we will
4 addressing ignition sources in the next Panel, and that
5 concludes my sort of a tutorial on flammability, and
6 I'd like to go on to reviewing the flammability
7 program.

8 As a result of these questions regarding this
9 accident, a number of programs were initiated on the
10 flammability of Jet-A fuel. The objectives and
11 progress of these programs are going to be reviewed
12 briefly here in terms of principal findings as they
13 relate to flammability conditions in the center wing
14 tank.

15 The objectives are shown on this slide, that
16 is, to try to determine the source of ignition and as a
17 backup position, fall back position, determine the
18 location within the tank, if possible, the ignition
19 source; and determine the fire and explosion properties
20 of Jet-A, and certainly determine the ignition energy.

21 To carry out this program, the Safety Board
22 enlisted a number of experts from around the world in
23 Fuel Chemistry, Fuel Flammability, Analytical
24 Chemistry, and Computer Modeling of Combustion
25 Explosions.

1 The first program we initiated to measure the
2 flammability Jet-A in the laboratory explosion chamber
3 was with the California Institute of Technology under
4 the direction of Professor Joe Shepherd. This program,
5 initial program, has grown well beyond the original
6 laboratory measurements to explore testing programs up
7 to a quarter scale modeling of the center wing tank.

8 The objective of this program, of course,
9 laboratory programs measure the rate of pressurized and
10 peak pressures and minimum ignition energy using Jet-A
11 fuel .

12 Almost simultaneously with this initial
13 testing program, the Safety Board contracted with the
14 University of Nevada at Reno to determine the vapor
15 pressure and vapor chemistry of Jet-A under different
16 conditions under the direction of Mr. Jim Woodrow.

17 These two programs were set up and operating
18 before a flight test program was designed and carried
19 out . The objective of the flight testing was to
20 determine the conditions inside the center wing tank
21 that led to the explosion. As we will hear, the
22 primary driving force for the flammability, of course,
23 is the air-conditioning packs underneath the tank.

24 When this flight test was designed, it was
25 decided to collect vapor samples at different times

1 during the flight test to determine the vapor
2 chemistry. These flight tests were probably the most
3 fundamentally important program that the Safety Board
4 carried out in helping you to find not only the
5 conditions inside the tank for guiding explosion
6 testing, but also to help us develop ways to reduce or
7 eliminate the risk of an explosion inside this tank.

8 The flight testing was done with the
9 assistance of the Boeing Company and Dr. Dan Bower will
10 review the flight test effort.

11 The decision to do vapor sampling inside the
12 tank during the flight led to the contract with the
13 Desert Research Institute at the University of Nevada
14 under the direction of Dr. John Sagebiel. Dr. Sagebiel
15 provided the expertise for this sampling and for the
16 analysis of that those samples.

17 Early in explosion testing at Cal Tech, it
18 was determined by the Safety Board that laboratory
19 measurements, although fundamentally important
20 understanding of what happens when Jet-A vapors are
21 ignited, such measurements by themselves could not be
22 used to determine how the center tank would react to an
23 explosive mixture on ignition.

24 As a result, large-scale or full-scale
25 testing was considered important. Because of the cost

1 and time of procuring multiple 747 wing tanks was
2 prohibitive, a quarter-scale testing of model center
3 wing tank was chosen to study the effects of partitions
4 in the tank, the effects of jetting between
5 compartments, and the effects of changing ignition
6 location within the tank.

7 Again, for this program, the Safety Board
8 turned to Cal Tech, Dr. Shepherd, and then also to
9 Applied Research Associates in Denver for this work.
10 Another fundamental issue drove the decision to do
11 quarter-scale testing.

12 The signature from an ignition source had
13 not, and has not, been identified in the investigation
14 of the TWA accident, and the question arose as to
15 whether or not an ignition at different locations
16 inside the center tank would result in different
17 outcomes in terms of the damage to the tank, and
18 whether or not an analysis of such damage would help
19 the Safety Board to identify the location of the
20 ignition within the center wing tank.

21 Simultaneously with the quarter-scale
22 program, it was decided to have a computer modeling
23 program interact with the experimental testing program.
24 The purpose of the modeling program was to facilitate
25 the testing program, and thus, reduce the amount of

1 experimental testing and to provide insights into the
2 effects of ignition location on explosion dynamics.

3 Consequently, the Safety Board contracted
4 with two separate facilities in order to use two
5 different computer modeling approaches. Sandia
6 National Laboratory in Albuquerque under the direction
7 of Dr. Mel Baer, was one of the programs chosen.

8 The second program selected was a joint
9 program with Christian Mickelson Institute in Norway
10 under the direction of Dr. Kees Van Win Gerden, and
11 with Combustion Dynamics in Canada under the direction
12 of Dr. Paul Thibault.

13 This is a very brief review of the rationale
14 for the experimental programs that were undertaken to
15 assist the National Transportation Safety Board in
16 investigation of this accident.

17 As you can see, we enlisted the assistance of
18 top experts worldwide to help us find the cause of this
19 accident. These programs had already provided
20 important information about Jet-A, and the conditions
21 inside the center wing tank that will lead to improve
22 aviation safety, and we believe continuation of these
23 programs will provide more information for improved
24 aviation safety.

25 That concludes my remarks, and I would like

1 at this point, to turn the program over to Dr. Dan
2 Bower, who will review the test flight program and
3 provide some of the flight tests results to guide us
4 further.

5 Dr. Bower.

6 Presentation By

7 DR. DAN BOWER

8
9 DR. BOWER: Thank you, Dr. Birky. Good
10 afternoon, Mr. Chairman.

11 As described in Dr. Birky's presentation,
12 flammability of a fuel vapor air mixture are dependent
13 upon the temperature, and pressure and the mixture.
14 Early in the accident investigation, it was recognized
15 that fuel air mixture existed in the center wing tank
16 of TWA 800 at the time of the accident.

17 We were able to determine from the flight
18 data recorder, altitude data, the pressure that existed
19 in the center wing tank at or near the time of the
20 explosion; however, based on the information known at
21 the time, no accurate assessment of the temperatures,
22 and hence, the level of flammability which may have
23 existed in the center wing tank is possible, and little
24 information existed about the typical temperatures
25 inside a center wing tank during normal flight

1 operations .

2 In order to accomplish our objectives in
3 testing computer modeling, the conditions that existed
4 in the center wing tank needed to be determined. In an
5 effort to determine the conditions that existed inside
6 the center wing tank, the Safety Board designed a
7 flight test program, leased a 747-100 Series Aircraft,
8 and performed an intensive series of flight tests.

9 The flight test program was designed to not
10 only determine the conditions that existed in the
11 center wing tank before the initial explosion, but also
12 to further the understanding of the heating process to
13 the center wing tank, understanding this heating
14 process may help to develop means of reducing the
15 temperature and enhance the flammability of the tank.

16 I will give a brief overview of the flight
17 test program and summarize some of the results obtained
18 during the flight test. An extremely large volume of
19 data was collected in these flight tests, and the
20 analysis of this data is still on-going.

21 The flight test program took place between
22 July 11th and 20th this past summer. Flight tests were
23 flown out of JFK Airport and coincided with the one-
24 year anniversary of the accident flight. Participants
25 in the flight test program were the FAA, Boeing

1 Commercial Airplane Company, Trans World Airlines, Air
2 Line Pilots Association, and Evergreen Airlines, the
3 owner of the test aircraft.

4 All of the parties participated in the review
5 of the flight test plan and were briefed on preliminary
6 results following each flight. As we stated, the main
7 objective of the flight test series were to obtain air
8 temperature measurements and pressure measurements
9 inside the center wing tank, also, in the wing tanks,
10 the vents from the center wing tank, and in the wing
11 tip surge tanks.

12 We also wanted to measure surface
13 temperatures on the external surface of the center wing
14 tank above the environmental control system units or
15 the air-conditioning packs, and we also wanted to
16 measure surface temperature measurements of the ECS
17 pack components.

18 We additionally want to measure.

19 CHAIRMAN HALL: What is ECS?

20 DR. BOWER: Environmental Control System,
21 another name for the air-conditioning packs.

22 Additional objectives of the flight test were
23 to measure the vibration of the center wing tank
24 bottom. We wanted to determine if sufficient vibration
25 existed to loft the liquid fuel. Lofting refers to the

1 shaking or the jarring of the liquid fuel enough to
2 create a mist or a small drop of the fuel.

3 DR. LOEB: Could you explain, Dan, the
4 relevance of that, please, the lofting the dynamics;
5 and if you can't, maybe Merritt should right now.

6 DR. BOWER: Perhaps Merritt can.

7 MR. BIRKY: Yes. One of the issues related
8 to the flammability of the tank is whether or not
9 vibrations and motion of the tank will cause small
10 droplets to come off the surface and be airborne, if
11 you will, into the tank and cause the tank to be an
12 explosive range or above the lower flammability limit
13 more than you would have just with the temperature
14 driving that.

15 If you go back and remember the curve I
16 showed you with the lines going off to your left with
17 altitude, those vibrations, the thinking was in some of
18 the literature, the older scientific literature, that
19 this would cause the tank to be in the flammability
20 range much more frequently than is normal in a case,
21 and so that was the reason for doing these vibration
22 tests on the test flight.

23 DR. BOWER: Thank you, Dr. Birky.

24 The Safety Board leased an aircraft from
25 Evergreen Airlines for the test. The leased airplane

1 was a 747-121 series aircraft, which was a similar
2 model to the accident aircraft, which was a Series-131
3 model, and the test aircraft was Boeing line number
4 106.

5 The Boeing Commercial Airplane Company
6 provided the instrumentation, installed the
7 instrumentation on the aircraft and the supervision of
8 the Safety Board, and also provided the flight crew for
9 the flight test series.

10 I would like to acknowledge the fine work
11 that the Boeing flight test group did in that group,
12 and we thank them. I also would like to acknowledge
13 the work of Mr. Robert Benzing, Mr. Bob Swaim and Dr.
14 Burke from the Safety Board in helping to develop the
15 flight test program and carry it out.

16 On the test aircraft we installed over 153
17 temperature sensors, or known as thermo couples.
18 Additional sensors were measured to measure pressure,
19 tank bottom vibration and custom equipment was designed
20 and installed to obtain vapor sample from the center
21 wing tank during the flight test.

22 Now, before I proceed with my presentation, I
23 just want to mention that some of the nomenclature I'm
24 going to use in my presentation just so we're familiar
25 with it in terms of the center wing tank. This views

1 is a top view of the center wing tank. We have the
2 Drive A in front. Bay 1 is referred to as the bay
3 between span wise beams 2 and 3. I will refer to bay 2
4 as the bay between span wise beam 2 in the mid spar.

5 The two bays between span wise beam 1 and the
6 mid spar referred to as the left and right mid bays,
7 and the bays between span wise beam 1 in the rear spar
8 is the F bays, and this is obviously mislabeled. I'm
9 sorry.

10 The ullage I am referring to is the space in
11 the fuel tank above the liquid fuel, which is occupied
12 by fuel vapor.

13 And now I'd like to show a quick video which
14 is going to detail some of our instrumentation
15 locations inside the center wing tank. Shown here in
16 this video, the white spheres represent the location of
17 our air temperature measurements inside the center wing
18 tank. See, we have several located in all of the bays,
19 and these are designed to measure the air temperature
20 in the ullage for the temperature of the fuel air
21 vapor.

22 As we move our view, we see the front two
23 bays. We have three trees of thermo couples, and then
24 the F bay center, we have three trees of thermo couples
25 measuring air temperature near the bottom of the tank,

1 the middle of the tank, and near the top surface of the
2 tank.

3 And as we move around we can get a good view
4 and idea of the relative temperature locations,
5 measurement locations. As we see from the pull out
6 view, we do not make any measurement in the Drive A;
7 only in the bays which contain the fuel vapor.

8 And I might add that what we have in this
9 video was only a portion of the temperature
10 measurements that were made on this tank and in the
11 airplane. We now spin the tank to examine some of the
12 instrumentation on the bottom surface. We have noted
13 in green some of the measurements were made on the
14 air-conditioning pack components, and the white disks
15 on the bottom of the tank represents surface thermo
16 couples to measure the temperature of the external
17 bottom surface of the tank.

18 Now, we did have additional measurement
19 locations in other parts of the aircraft also. We
20 switch back to a top view. We see two of the thermo
21 couples to the right; they are located in tank 3, and
22 we will have a better view of that in a second.

23 Now this view shows the fuel tanks, the
24 schematic of the fuel tanks in both the wings. The
25 little square at the end of the wing tips represent the

1 search tanks in the wing tips, and we have shown one of
2 the vent stringers, which is a vent leading from the
3 center wing tank out to the search tank, and we have
4 measurements inside that search tank at the wing tip.

5 (Pause)

6 DR. BOWER: And as we spin the tank back, we
7 have another view of the thermo couples represented by
8 the green squares on some of the air-conditioning pack
9 components, and we see we have a good relative location
10 of some of the surface thermo couples on those pack
11 components, and as you notice on the one side, there
12 are more than the other, and that side represents the
13 side of the airplane which housed two of the air-
14 conditioning units, which from the top view is the left
15 side, as you can see here.

16 The entire flight test program consisted of
17 nine flights. For each of the flights, balanced weight
18 was added so that the gross airplane weight was the
19 same as TWA 800. The fuel load and the central for TWA
20 800 was duplicated in each flight as closely as
21 practical.

22 Different combinations of the air-
23 conditioning packs were used to provide different heat
24 loads to the center wing tank in each flight, and one
25 flight was strictly dedicated to replicating the

1 preflight operations and flight conditions of TWA 800,
2 and to prevent the center wing tank explosion from
3 occurring on the flight test, prior to the beginning of
4 the flight test series, the entire center wing tank was
5 fully inspected to ensure that no ignition sources were
6 introduced or existed in the center wing tank.

7 Now, for these flights, 50 gallons of liquid
8 Jet-A fuel was placed in the center wing tank. The
9 Jet-A fuel used in these flights was loaded onto a 747
10 at Athens, Greece, and flown on a regular service
11 flight from Athens to JFK Airport. The Jet-A fuel was
12 offloaded from the regular service airplane,
13 transported, and 50 gallons was loaded into the center
14 wing tank of the test aircraft prior to the first test
15 flight. This fuel remained in the center wing tank for
16 the first four test flights.

17 As described previously, one of the major
18 objectives was to obtain vapor samples at the different
19 temperatures and pressures which occur in the center
20 wing tank during an ascent and near the TWA 800
21 accident altitude. On three of these flights, which
22 had the liquid Jet-A in the center wing tank, vapor
23 samples were obtained on the ground during taxiing, as
24 the airplane reached 10,000 feet, and as the airplane
25 passed through 14,000 feet.

1 Dr. Sagebiel will discuss in more detail the
2 analysis of the vapor samples obtained in the flight
3 test. Liquid samples of the Jet-A fuel were drawn from
4 the center wing tank several times in the flight test
5 program, including one sample before the test program
6 began.

7 Mr. Woodrow will address the analysis of
8 these liquid samples.

9 I am now going to address the results from
10 one of the flights, which is referred to as a TWA 800
11 emulation flight. The conditions, preflight
12 operations, taxi and take-off of TWA 800 were
13 replicated as closely as possible in the emulation
14 flight. The flight was performed prior to the
15 emulation flight, which flew up to 35,000 feet and
16 landed at the same time as the accident airplane
17 previous flight, TWA 881.

18 Upon completion of taxiing from that flight,
19 the environmental control system units, or the
20 air-conditioning packs 1 and 3 were placed in
21 operation. These units remained in operation for the
22 entire ground portion of the emulation flight, or for
23 approximately 3-1/2 hours.

24 Efforts were made to perform all preflight
25 operations at the same time of day as TWA 800,

1 including loading the fuel, pushback and start of
2 taxiing. The lift off of the test flight occurred
3 within one minute of the time of lift off of TWA 800.

4 Shown in this block is a comparison of flight
5 test altitude time history as compared to the data
6 recorded on the TWA Flight 800 flight data recorder,
7 and altitude as a function of time, and we see that the
8 current lift off, the flight crew matched the central
9 file exceptionally well, including the slight level off
10 of 6,000, level off of a slight descent, 13,000 back to
11 12,800, and up to the event altitude.

12 The test flight crew matched the central file
13 while they reached the explosion altitude of TWA 800
14 within ten seconds.

15 I will now show animation that will take some
16 of the data collected in this test and the same format
17 as previously done. Now, this animation will begin at
18 the start of the on ground portion of the test, that
19 is, when the pack 103 were turned on. The time is
20 accelerated on the video quite a bit, and on the right-
21 hand side of the animation is the temperature scale,
22 represents the temperatures and the measurement
23 locations only.

24 The color of the tank structure does not
25 represent the temperature of the structure, and as we

1 run the pack, we see that the left side starts becoming
2 warmer before any other portion of the tank. Now, the
3 warmer temperatures we measured in the tank at the
4 start of flight test pack. I will hold the animation
5 here and go into some of the temperatures that we
6 reported.

7 I zoom in now to the left side mid and half
8 bays, the temperatures ranging from 123 to 145 on the
9 left mid, moving up to the bay 2, bay 1. In bay 2 we
10 have 128 degrees at the bottom and 119 at the top.

11 Now, we will pull back and examine the
12 temperatures on the bottom of the center wing tank.
13 The color scale was somewhat limited. so anything that
14 is above 240 is represented by flash, and this on the
15 bottom, that we range anywhere from 140-to-200 degree
16 on the bottom surface of the center wing tank starts
17 the flight test tank.

18 Now we examined some of the temperature
19 measurement on some of the air-conditioning components.
20 You see we ranged from 135-to-370 degrees.

21 We are now going to continue the test,
22 continue the animation and follow the time of the test,
23 and an inset showing flight test airplane will appear;
24 however, because of the accelerated time, the motion of
25 the airplane will appear to be erratic.

1 Now, the first vapor sample was taken on the
2 ground during taxiing, and as we start to go, as we
3 rotate, I'm holding animation. Notice the outside air
4 temperature was 87 degrees. Continue now in the
5 animation of the ascent of the flight test airplane.
6 The airplane climbs. There is a slight relaxation of
7 cooling of some of the temperatures in the tank. You
8 notice a left path a left lid had gone from a bright
9 read to more of an orange.

10 And when we cross 10,000 feet, the second
11 vapor sample on this flight was taken. That data all
12 the way, we show data at the same altitude is the TWA
13 explosion. The test airplane passed the 14,000, that's
14 when the third vapor sample was taken. The center wing
15 tank pressure was measured at this altitude of 25-9
16 atmosphere .

17 We examine some of the temperatures measured
18 at this altitude. You see in the rear, it ranges
19 between 120 and 113, and 127 and 114 in the mid bays.
20 The forward center of the forward two bays, it ranges
21 between 115 and 120 degrees, and when we examined some
22 of the measurements on the side of the tank, which are
23 four inches from the side log, we see a slightly cooler
24 temperature on the side walls, near the side walls.

25 We got out and examine a few of the

1 temperatures we made in the tank. We have a wing tip
2 surge tank temperature of 68-to-78 inside tank 3.

3 And that concludes the animation.

4 Since that went by fairly quick, I want to
5 review some of the key results from this flight test
6 that we detected in this animation.

7 I noted in the color shading in the
8 animation, maximum temperatures occurred in the center
9 wing tank ullage immediately before the start of
10 taxiing. Before I get too far here, I just want to
11 mention, the animation that I showed and the animations
12 that were showed yesterday, I just want to acknowledge
13 the work of Mr. Doug Brady and Mr. Dan Vance, the NTSB
14 Performance Division, for all their hard work in
15 preparing these excellent videos. Also, Mr. Todd Frank
16 for engineering the animation. I want to thank them
17 for taking care of all of the animation; excellent
18 results.

19 Examining the center wing tank ullage
20 temperatures at the start of the flight test, which
21 noted in the animation, when the ullage was at its
22 warmest, we would be examining the temperatures going
23 from the rear forward in the left aft bay, left mid
24 bay, the center of bay 2 and the center of bay 1.
25 We're going to be looking at the temperature

1 measurements, the lower temperature measurements
2 immediately above the floor in the center on the upper.

3 You see the left aft bay from a fairly good
4 range from top to bottom, there is a fairly decent
5 rating. The left mid bay, the maximum is about over
6 145 degrees. There was a similar rating at the bottom,
7 getting considerably warmer than the ratings at the
8 top. The forward two bays showing a similar rating,
9 however, not as pronounced; however, there is
10 considerable rating from the left rear side of the tank
11 to the forward part of the tank, particularly in the
12 left side.

13 And again, as I stated previously, that is
14 the side that houses two air-conditioning units
15 underneath the tank.

16 Now, this next plot shows similar
17 measurements. We took temperatures on the test
18 aircraft at 13,300 feet altitude. This condition best
19 represents the conditions that existed in the center
20 wing tank of TWA 800 at the explosion. We are looking
21 at the same measurement location, different altitude.
22 The left aft bay ranges between 120 and about 113.
23 That is still a considerable rating in the left mid bay
24 with maximum temperatures of 127 degrees at the bottom.
25 The center of bay 2 shows a maximum of about 120.

1 Center bay 1, you see, has a similar distribution.

2 Some of the key findings from these
3 simulations, first the temperature of the center wing
4 tank went up to 127 degrees Fahrenheit, and that was in
5 the left mid bay, 13,200 feet altitude. The
6 temperature rating existed throughout the entire on
7 ground taxiing and ascent portion of the flight, and
8 some of those ratings were a fairly good size.

9 The vibrations we measured was well below the
10 previously defined -- for any liquid fuel.

11 Now, we are going to briefly discuss the
12 results of another flight test in the series. In this
13 flight test two environmental control service units,
14 systems, units were run for 90 minutes prior to take-
15 off; 12,000 pounds of liquid fuel loaded into the
16 center wing tank immediately before the start of
17 taxiing. The same TWA 800 the central file was used
18 for this flight, also.

19 Hence, the only parameter varied from the
20 varied from the emulation flight to this test were the
21 reductions in the air-conditioning pack operation time
22 and the addition of the fuel to the center wing tank
23 made before taxiing.

24 Now, this chart is a little busy, so I'm
25 going to try to explain what everything here is. This

1 is a plot of temperatures as a function of the lab's
2 test time showing temperatures, the function of
3 temperatures as a function of time for the two test
4 flights.

5 These curves up here (indicating) represent
6 TWA 800 simulation flight. The lower curves represent
7 temperature measurements with the 12,000 pounds of fuel
8 in the center wing tank. This comparison is for the
9 measurements in the left aft bay and represents three
10 vertical positions, the lower measurement, the central
11 measurement and upper measurement.

12 You see the initial heat up portion in the
13 simulation flight up to the start of taxiing and the
14 lift off is noted right here, a slight reduction of TWA
15 800 altitude. On the flight with 12,000 pounds of fuel
16 in the center wing tank, you see the same initial heat
17 up of the tank of the ullage, and then the fuel is
18 added to the center wing tank.

19 After the fuel is added, this lower probe is
20 immersed in liquid fuel, and you see that the lapsed
21 time of this entire test is much shorter than the
22 reduced pack operation time before lift off. After the
23 fuel is added and the taxiing, you see that the ullage
24 remains somewhat constant.

25 Now, this next slide is a comparison of these

1 temperatures of the center wing tank bay 2. Both test
2 flights were at explosion altitude, 13,800 feet, and
3 the results shown here is typical of all the bays. In
4 the center of bay 2 the results from emulation flight
5 is 50 gallons in the center wing tank. The lower probe
6 measured close to 120 degrees; 12,000 pounds of fuel in
7 the center wing tank at the explosion altitude; the
8 temperature was reduced to about 96.

9 In this probe, the 12,000 pounds of fuel in
10 the center wing tank was immersed in liquid fuel. The
11 next upper measurement of the center probe was
12 approximately 117, liquid fuel and the pack operation
13 that was reduced to less than 85 and dropped. And the
14 upper measurement shows similar behavior.

15 MR. SWEEDLER: Dr. Bower, just a point of
16 clarification: These last two meetings, were they also
17 immersed in jet fuel?

18 DR. BOWER: No, sir. These were actual
19 ullage measurements.

20 MR. SWEEDLER: Thanks .

21 DR. BOWER: You're welcome.

22 Mr. Chairman, this concludes my presentation.

23 MR. BIRKY: Now, I'd like to go over to Dr.
24 Shepherd and let him start on the laboratory
25 measurements of Jet A explosions.

1 Dr. Shepherd.

2 DR. SHEPHERD: Thank you, Merritt.

3 We have to wait a minute to warm our
4 computer. Someone kicked the plug out.

5 (Pause)

6 CHAIRMAN HALL: While we're waiting for Dr.
7 Shepherd, Dr. Birky, will you and Dr. Bower sort of
8 summarize for us, the presentations? What time is the
9 fuel within the flammability range?

10 MR. BIRKY: I think we're going to come into
11 that with a presentation, a brief presentation by Dr.
12 Sagebiel and Mr. Jim Woodrow in terms of the
13 significance of those temperature measurements, and
14 significance - more significance - of the sampling that
15 was done from that tank during the light process that
16 data is involved, then I analyze and am available for
17 discussion after Dr. Shepherd, I think.

18 How are you doing, Dr. Shepherd?

19 DR. SHEPHERD: I'm doing good.

20 MR. BIRKY: Okay.

21 DR. SHEPHERD: Okay, I'm ready to go. I
22 apologize for that interruption.

23 MR. BIRKY: No problem.

24 CHAIRMAN HALL: As long as it didn't crash.

25

1 Presentation By

2 DR. JOSEPH SHEPHERD

3
4 DR. SHEPHERD: Good afternoon, Mr. Chairman,
5 Ladies and Gentlemen:

6 The explosions Dynamics Laboratory became
7 involved in this crash investigation in the Fall of
8 last year at the request of Dr. Birky.

9 Since that time, we have carried out a number
10 of studies on Jet A and the conditions of TWA's flight.
11 Our work is still in progress, and as we meet here this
12 week, my colleagues are carrying out experiments that
13 will help us learn even more about this explosion that
14 will tend to teach us how to prevent accidents in the
15 future.

16 Today, I would like to inform you about the
17 activities we have been involved in over the last year
18 of our findings.

19 Our primary goal has been to assist the NTSB
20 in determining the crisis of the explosion, the cause
21 of the explosion, and in the process of pursuing that
22 goal, we had to learn a great deal about Jet A.

23 Despite over 30 years of using Jet A in commercial
24 aviation and Jet 8 with Military aviation, two fields,
25 I might add, are essentially identical, the amount of

1 data on flammability and explosions is rather meager.

2 At the time we began our investigation, we
3 acknowledged there were primarily three separate
4 studies that have been carried out in 1967, 1970 and
5 1971. None of these studies dealt on the specific
6 issues that are a part of the Federal investigation.
7 For this reason, we have been compelled to carry out
8 studies to unravel the physical chemistry of Jet A, the
9 conditions in the center wing tank, the effects of the
10 airplane operation on the flammability of the fuel, and
11 finally, the initiation and the development of an
12 explosion in the center wing tank.

13 My presentation will describe the key ideas
14 and results of our studies in the Jet A flammability
15 explosion. I use the term "our," because this has been
16 a team effort. We have been together with our
17 colleagues of other institutions, some of which is
18 representative here today, all under the technical
19 leadership of (inaudible) .

20 The question is necessarily technical, and in
21 some ways incomplete. It is important to note that in
22 the process of our investigation, we have learned
23 already a great deal, and I believe this knowledge will
24 not only help us unravel what has been described as TWA
25 800, it will also benefit aviation safety.

1 Here is the plan of my presentation this
2 afternoon. First, I would like to share with you the
3 main questions you set out to answer last year when we
4 began our investigation. Second, I will discuss the
5 specific types of activities to be understood what the
6 answer is. Third, I will present the key findings of
7 our studies.

8 I would like to remind you at this point of
9 some key facts surrounding this incident in order to
10 motivate the public in our studies. From the crash
11 investigation that you have heard about already
12 extensively, we know that the initiating event was an
13 explosion (inaudible) .

14 There are three elements that had to be
15 present, as Dr. Birky described in his introduction in
16 order to have the fire and explosion. Those are fuel,
17 oxidizer, and ignition. But these three elements are
18 not enough. In addition, the fuel and oxidizer have to
19 be mixed together in direct proportion so the plane can
20 move through the mixture.

21 And further, the ignition source must be
22 located within the flammable mixture.

23 Finally, at the point you have to burn the
24 mixture, put the pressure inside the tank and build
25 up . In the center wing tank, the fuel is necessary for

1 the explosion. It was a residual amount, and I am
2 going to use 50 gallons that is representative of the
3 (inaudible) .

4 However, the amount of fuel that was
5 vaporized and present with gas mixed with air was
6 unknown; but the oxidizer portion provided by the
7 oxygen, which was 21 percent of the error -- if you
8 look at the tank in my diagram, you will notice that
9 the fuel indicated by the green material on the floor
10 of the tank, some aspects of the tank are represented
11 by the other (inaudible) .

12 Some of the key things that we have already
13 heard about in the previous presentations from the
14 flight testing that are important as the heating
15 underneath the tank, that those heated up the fuel.
16 That resulted in the vaporization of the fuel, creating
17 a fuel vapor.

18 Some of that mixture was vented out of the
19 tank as the airplane climbed up to the altitude of
20 13,000, at which point there was an explosion, and the
21 ignition source is at present not known. Other groups
22 in the investigation concentrated on the ignition
23 source, leaving us to consider the issues that are
24 related to flammability, ignitability, and the build up
25 of explosion in the tank.

1 As far as I know, the propagation of a plane
2 to a complex structure like this is not going to
3 (inaudible) . Our work then is focused on the following
4 issues: First of all, we needed to identify the amount
5 and the condition of the fuel that was present in the
6 center wing tank.

7 Second of all, we wanted to determine a
8 measure of the ignitability of the fuel, and the
9 conventional way to do that is to look at the minimum
10 energy required to spark ignition. That doesn't mean
11 that a spark ignited the explosion. It is for us to
12 find the way to (inaudible) .

13 Third, we wanted to determine what the
14 maximum pressure possibly was.

15 Four, we wanted to examine issues related to
16 the propagation of the point in the center wing tank.
17 The last two items, of course, are key elements to the
18 crash investigation. What did we learn from the
19 wreckage around the ignition location? This speaks to
20 the issue of, is there a characteristic signature that
21 is developed by this explosion, and from that
22 signature, is it possible to identify the location
23 where the explosion --

24 I'm going to be speaking in this portion of
25 my talk about the first three elements here, and I have

1 a separate presentation a little later on on the
2 propagation (inaudible)

3 so, let's consider then the mounting position
4 of the fuel bracer on the tank. The key issue, of
5 course, is why was the center wing tank flammable? And
6 as we heard in Dr. Bower's presentation, it's the
7 heating by the air-conditioning unit that causes the
8 evaporation of the fuel, and in addition, the climbing
9 of the airplane to an altitude of 14,000 feet created a
10 more favorable mixture, with less air.

11 How the quantify that, how to express that in
12 numbers allows us to evaluate this relative risk of
13 hazards of propagating the center wing tank. Well,
14 there are two ways we can go about that.

15 One is by direct measurement in a flight
16 test, and that is done (inaudible) . He is going to be
17 speaking about that, and another way to do this is to
18 carry out laboratory tests of the fuel and use results
19 of the flight test and the modeling of the center wing
20 tank to project the amount of the fuel vapor that is
21 present.

22 so, it's necessary then to understand how
23 much of that liquid Jet fuel was turned into vapor, and
24 that issue in scientific and technical terms is, what
25 is the vapor pressure of that fuel?

1 In addition to the vapor pressure, we have to
2 know something about the chemical makeup of those
3 vapors . Jet A is a complex substance that is well over
4 100 different types of molecules which all have
5 different shapes and sizes, and therefore, we really
6 needed to understand that. It has not been understood
7 at that level of heat before, and we need to understand
8 that and fly that airplane.

9 But, we did, and so, Dr. Woodrow at the
10 University of Nevada, worked on that aspect of the
11 testing.

12 Now, I'd like to say a little bit about
13 flammability, just to recap what Merritt said earlier
14 in my own terms and to emphasize these concepts because
15 this is the key idea that we're dealing with here.

16 Flammability means that you have the right
17 proportions of fuel and oxygen molecules in the plane.
18 We measure flammability in terms of limits of
19 flammability. That's given usually in terms of the
20 amount of fuel. The amount of fuel can be expressed as
21 a percentage by mass, or a percentage by volume,
22 however you would like to do it.

23 The two figures down on the bottom show that
24 as we added fuel to this mixture we progressed from a
25 region where we don't have enough fuel to have

1 combustion at the site, that's on the left-hand side.
2 And there is so-called lower limit flammability, and
3 there is a region in which the mixture is explosive,
4 and then if we have too much fuel.

5 Our concern here today is with the lower
6 limits of the plane. The vapor pressure in Jet A is
7 very low. In fact, ordinarily, no one measures the
8 vapor pressure in Jet A because the standard test
9 techniques that are available for doing that, don't go
10 that far. So, we had to develop special techniques to
11 do that.

12 Here is the idea that we had in mind at our
13 laboratory tests. We would use the data from the
14 flight tests to give us the temperature at the time.
15 We would measure the vapor in the laboratory. We would
16 make some evaluation of the mixing and the evaporation
17 that occurs within the tank during the climb, and that
18 was done by engineering analysis by using the data from
19 the flight test sample.

20 Then we would calculate the amount of fuel
21 vapor. As a rule of thumb, the amount of fuel vapor,
22 when you measure it in ratio to the amount of air, so
23 you calculate this part we are going to call F, fuel
24 air ratio, classic fuel vapor and classic air. We are
25 now talking about just the content of this center wing.

1 When that exceeds three-hundredths mixture, how do we
2 calculate that if we know the vapor pressure?

3 Well, the equation on the lower right-hand
4 corner, it says that if we multiply the vapor pressure
5 times the volume of the tank divided by the
6 (inaudible) .

7 That is why we have emphasized knowing what
8 the vapor pressure is in our work. Vapor pressure is a
9 very simple idea. Everybody is familiar with it
10 because when you heat up your kettle on the stove, you
11 make steam. The steam is actually little droplets that
12 you can see. Ordinarily, you don't see vapors. When
13 you go to the gas station, you smell them when you fill
14 up your gas tank if you have some place where there is
15 not a vapor recurring system.

16 The simple idea is, if you heat up the fuel
17 that causes the few molecules to become more energetic,
18 and they escape the liquid and they evaporate to form a
19 vapor or gas. The collisions of those molecules with
20 the walls produce a force, a pressure, and we call that
21 vapor pressure.

22 Now, that's a property of the fuel. That
23 means that if you have a certain fuel, and you have a
24 certain temperature, you can measure that, but there
25 are some complicating factors which are particularly

1 important for this case. One is that, that is a very
2 strong function of temperature. So, as the temperature
3 changes by 20 degrees, you have a very large change in
4 the vapor pressure, which is extremely significant for
5 flammability.

6 The other property of a fuel like Jet-A is
7 that as you increase the amount of fuel in the tank,
8 the vapor pressure increases. That's not the case with
9 simple substances, like water. The additional problem
10 is that when the fuel sits out for a long time, or has
11 been flying in an aircraft, sitting in the tank for 15
12 hours, that also can change the vapor pressure, and
13 there is not a simple method to estimate or calculate
14 the vapor pressure because Jet A is such a complex
15 fuel .

16 At the time we started our investigations,
17 there was no reliable data available, and so we set out
18 to make measurements over a temperature range between
19 zero and 60 Celsius, or 32 and 140 Fahrenheit, and we
20 did that as a function of the amount of fuel. We
21 varied it roughly from what would correspond to a half
22 full tank to a center wing tank that only had 50
23 gallons in it.

24 the key thing about this is, we did this with
25 a small amount of fuel. That hadn't been done in the

1 past, but that's important because as you reduce the
2 amount of fuel, you reduce the vapor pressure. You
3 might think that the tank might not even be flammable
4 because it had such a small amount of fuel in it.

5 Well, that's not the case, it turns out. The
6 other thing that is important is understanding what
7 happened to that fuel after it was loaded on the plane
8 in Athens, and then it flew over to Kennedy, and then
9 took off again. That's the issue of weathering. We
10 will hear a little bit more about that later today.

11 I have already spoken about the business of
12 chemical composition, and we will hear some more about
13 that.

14 Well, all of those factor aside, we have gone
15 into the laboratory, and we have measured the vapor
16 pressure of Jet A, and these are the results. This
17 plot shows the pressure. The units are a little bar.
18 What does that mean in ordinary terms? Those are
19 thousandths of an atmosphere. So, that scale ranges
20 from zero to 20 thousandths of two-hundredths of an
21 atmosphere. It doesn't seem like much, but that's all
22 that it takes, in fact.

23 And the temperature ranges from 32 to 140
24 Fahrenheit. Now, what does that mean in terms of this
25 problem at hand? Well --

1 MR. BIRKY: Joe, could you just explain what
2 an atmosphere is so that the audience will understand
3 that, please?
4

5 DR. SHEPHERD: An atmosphere is the pressure
6 of the air right here in this room today. So, in
7 common units, it's 14.7 psi.

8 The significance is that over on the right-
9 hand side, you see an arrow that shows the range of
10 flammable mixtures in terms of that partial pressure.
11 We see that anything with a partial pressure above
12 about 4 millibar would be flammable at 14,000 feet.

13 Now, if we then superimpose upon that range
14 of temperatures that were measured in the flight test
15 and reported by Dr. Bower in his presentation, we see
16 that there is a very substantial overlap between those
17 two conditions. So, we would expect, on the basis of
18 this simple evaluation, that it would indeed be
19 flammable.

20 Now, I have shown two sets of data here. The
21 green points correspond to the half full tank, and the
22 yellow points correspond to the 50 gallons, and we see
23 in both cases that for the flight test temperatures
24 between 100 and 140 Fahrenheit, we have a flammable
25 condition.

1 That's what we estimate. Now, here is a
2 little bit more quantitative application of that. If
3 we imagine that we had 50 gallons of liquid fuel,
4 that's about 330 pounds, if we work out our formula and
5 we calculate how much we had in vapor in the center
6 wing tank, that's about 4 pounds. Four pounds of fuel
7 is a very small amount of liquid fuel. It's something
8 about two-thirds of a gallon had to vaporize to form
9 up. That would be at a reference temperature of 50
10 degrees C., which in the middle of the range of
11 temperatures that were measured in the flight test.

12 Now, by comparison, the massive air in that
13 tank is about 120 pounds at sea level, but when we go
14 up to 13,800 feet, as Dr. Bower pointed out, the
15 pressure drops down to 60 percent of the value at sea
16 level, and therefore, we have a little bit less air.
17 We only have about 70 pounds, and if we take the ratio
18 of those two, then we can get a notion about what the
19 fuel air ratio would be, and that's shown here on this
20 figure (indicating) .

21 The red line is the .03, the three-
22 hundredths. That indicates the flammable condition,
23 and I have shown as a function of temperature then, the
24 fuel ratio to be predicted by this analysis, both at
25 sea level and at 14,000 feet.

1 The important thing to note is that at sea
2 level, the tank doesn't become flammable until the
3 temperatures reach around 120 degrees Fahrenheit, or
4 about 50 degrees Celsius, but at 14,000 feet, it
5 becomes flammable when you've above 30 degrees Celsius
6 or something on the order of about - I will give you
7 the exact number here - 86 degrees Fahrenheit.

8 Now, those vapor pressure measurements are
9 only a rough guide to explosion hazard. In general,
10 the explosion hazard of a combustible liquid increases
11 as the vapor pressure increases; but it's desirable and
12 necessary to have a direct measurement of the
13 flammability of this material, and as Merritt pointed
14 out in his introductory comments, that's usually
15 measured by a so-called flash point test.

16 Flash points for Jet A are typically in the
17 range of 45-to-50 C. for the Jet A we tested in our
18 laboratory, but we have found that a flash point is not
19 a particularly useful concept for Jet A when you're
20 considering ignition by sources like sparks, because
21 the explosions can occur down to much lower
22 temperatures.

23 That's because the flash point test is done
24 with an open flame as the ignition source, and to start
25 with an open flame over a very small hole, you

1 basically take a cup full of fuel, and you heat it up
2 from the bottom, a small cup, and it has a little hole
3 in the top. Slide back a little sligher, and you just
4 dip down the flame and see if there is literally a
5 flash - poof. That's how the flash point test works.
6 That test is very useful for ranking materials relative
7 in hazard to one another, but it does not give you an
8 absolute measure of the ignitability or flammability of
9 fuel vapor.

10 so, we felt that explosion test inside of a
11 vessel with fuel vapor and air under the conditions of
12 the center wing tank at the altitude of 13,800 feet,
13 that is a pressure of 6/10 of an atmosphere, and at the
14 temperatures over the range which span what was
15 measured in the flight test were important to do.

16 This is a standard data on flammability.
17 There has been work done on this in the past, for
18 example, this is the work that was done in 1967 by
19 Nestor, but the important thing here is that his work
20 used a tank which was one-quarter-to-one-half full, did
21 not have the 50 gallon type equivalent, and in
22 addition, he used a very strong ignition source. This
23 is the ignition source of 12-to-24 jewels, and it was a
24 repetitive spark.

25 Now, what does that mean - 12-to-24 jewels?

1 We spent a lot of time trying to give some sense to
2 these numbers in terms of dropping objects and the
3 energy that's available in your cellular pager and so
4 forth. I would suggest that one way to think about
5 this is when you have a short circuit in your household
6 wiring, and you get a very strong spark and you blow
7 out your circuit breaker. This is the sort of energy
8 that can be involved in that.

9 SO, we felt it was important for that reason
10 to do new work in this area. We wanted to find the
11 lowest energy that you needed to ignite a given
12 mixture. We wanted to do tests with weathered fuel.
13 SO, we set out to do that, and the standard way of
14 doing that is to use a small spark, a single spark, not
15 a repetitive spark; to do it inside of a vessel where
16 you can actually visualize what's happening to see
17 whether or not you get ignition.

18 And to be able to examine the range of types
19 of fuels, looking at fresh versus weathered fuels, and
20 fuels from different sources. We have so far worked
21 primarily on fresh fuel, although work on weathered
22 fuels in progress.

23 This is the type of vessel that we do this
24 experiment in. This is a rectangular steel box that's
25 strong enough to contain an explosion. There is a pair

1 of electrodes that are indicated here, and we discharge
2 a capacitor which is charged up with some electrons
3 through that gap, and makes a little spark. When the
4 spark is strong, it's a flight flash. When the spark
5 is weak, you can hardly see it. You have to turn out
6 the lights to see it.

7 And we fill up the bottom of this vessel with
8 a small amount of jet fuel, and then you can see there
9 is some heating tape that's wrapped around it, and that
10 heating tape provides the energy to warm up this vessel
11 to the appropriate temperature, and when we do the
12 experiment, it's inside of a box, and we control the
13 temperature very carefully so we understand what we
14 have. There are some connections up there on the top
15 so we can introduce fuel and remove it.

16 This is a picture of what you see. If you
17 look at the flame, using a particular kind of
18 visualization, that's basically a very strong light
19 source from the back, and there is a spark that occurs
20 across the lower set of electrodes. The upper set of
21 the electrodes were not used in this experiment.

22 And you can see a spherical shape which is
23 growing from the bottom, and these pictures go from
24 left to right, top to bottom. That is the flame itself
25 growing, moving into the mixture, and as the flame

1 grows, the flame becomes unstable, that is, you can see
2 those lines on the surface and eventually down at the
3 bottom it looks very wrinkled.

4 This was not done with Jet A. We have done
5 some visualizations with Jet A, but it's very hard to
6 do because it condenses on the windows, and we don't
7 see a good picture. So, this was done with a simulant,
8 which I will be discussing later in connection with the
9 core skill test.

10 When we do these tests then, what we do is,
11 we look to see if we get such a flame. We also measure
12 the pressure. That gives us two ways to tell if there
13 was in fact an explosion inside of the vessel, and then
14 that gives us a point on our flammability diagram. And
15 we do this over and over again. We had to do hundreds
16 of tests to define flammability. It's very tedious to
17 do when you do it with jet fuel because every time you
18 do it, you have to take the jet fuel out. You have to
19 clean out the whole container and start all over again.

20 If you don't do that, you're not going to get
21 accurate results because even the very small amount of
22 combustion you get every time you have a spark in there
23 will change the chemical composition.

24 These are the results. This graph shows the
25 amount of energy in the spark that was put in as a

1 function of the liquid temperature, and we have data
2 here from several different mass loadings. Our results
3 indicate that the mass loading, that is, the amount of
4 fuel, is not particularly significant for the ignition
5 energy. That's one of the important findings that we
6 have made.

7 The other finding that we made is that there
8 is an extremely strong dependence of the ignition
9 energy on temperature. This is a special type of plot.
10 Every increment on the left-hand side is a factor of
11 10. That means the energy that we have at the top of
12 this plot is 100,000 times larger than the ignition at
13 the bottom.

14 so, increasing the temperature from 30-to-55
15 or 60 degrees Celsius, which corresponds with 86-to-14-
16 Fahrenheit, increases the risk of explosion from a
17 spark for a factor of 100,000. That's a very strong
18 dependence. It's typical of fuel mixtures.

19 All of the previous testing has been done
20 with over on the left-hand side of that graph, and as
21 we see, this strong dependence has very significant
22 implications for this investigation.

23 Now, I'd like to turn to the final topic of
24 this presentation, and that is, looking at the maximum
25 explosion pressure. The maximum explosion pressure,

1 that is, the pressure that is developed when you have
2 an ignition, determines the forces on the structural
3 members of the wing tank, and those forces will then
4 determine whether or not it fails.

5 We measured those pressures at Cal Tech in
6 our explosion test vessels. That vessel that I just
7 showed you was a very small vessel, but we have much
8 larger vessels that we've also done this experiment on.
9 The main parameters we've looked at are the fuel mass
10 floating, that is, how full the tank is with fuel. We
11 looked at the equivalent of 50 gallons up to a quarter
12 full .

13 We have looked at this as a function of the
14 fuel and air temperature and as a function of the
15 amount of turbulence in the vessel.

16 This is the picture of the vessel, and it
17 abuts the tank, if you can't tell the difference
18 between me and the vessel. The result of those types
19 of experiments are pressure time traces, which are
20 measured with special pressure transducer and the
21 digital recording system, and I have shown here results
22 from Jet A at three different temperatures.

23 so, we have 40 degrees Celsius, that's 104
24 Fahrenheit, 50 degrees; that's 122 Fahrenheit; and 60
25 degrees, that's 140 Fahrenheit. You can notice the

1 progression as you increase the temperature, the peak
2 pressure increases.

3 MR. BIRKY: Joe, may I interrupt you. Can
4 you go back to that slide, and would you do a
5 comparison of those pressures with what the strength of
6 the tank is so that the people know what that reference
7 point is?

8 DR. SHEPHERD: Yes. Thank you, Merritt.

9 On the right-hand side in blue are shown the
10 scale in psi, and this is the pressure increase, so
11 we're measuring it starting from the initial pressure
12 in the vessel, and I should point out, that was 6/10 of
13 an atmosphere corresponding to the explosion altitude.

14 And I believe in round numbers 20 psi has
15 been used as the strength of the weakest structural
16 members, and we can see in all cases these peak
17 pressures exceed that value, and in some cases, by more
18 than a factor of 2.

19 CHAIRMAN HALL: More than a factor of what?

20 DR. SHEPHERD: Two or three.

21 This actually illustrates your point in a
22 little bit different way. Here, I plotted the peak
23 pressures as a function of the amount of liquid fuel
24 that was in the tank, and I have indicated with this
25 arrow over on the right-hand side the lowest failure

1 pressures. These pressures are measured in a slightly
2 different way. These are absolute pressures, not
3 differential pressures, so the arrow is located in a
4 little bit different location.

5 You can see that when you have very low
6 temperatures, there is an effect of the small amount of
7 fuel, but once we get above about 40 degrees C., or 100
8 degrees F., there seems to be very good agreement in
9 between the two types of fuel loadings, and the
10 pressures that we would predict for the temperatures,
11 range of temperatures that were measured in the flight
12 test, those peak pressures range from on the order of
13 50-to-60 psi, which is substantially higher than the
14 failure pressure we were just discussing.

15 DR. BOWER: Excuse me, Dr. Shepherd.

16 DR. SHEPHERD: Yes.

17 DR. BOWER: On that previous plot, I'm having
18 a little hard time reading those numbers on the right-
19 hand side.

20 DR. SHEPHERD: I'm sorry. That's a poor
21 choice of colors, I'm afraid, for that slide. It
22 starts at 15. The next one is 29. Let me see if I can
23 do this. It starts at 15, then 29, 44, 59 and the top
24 is 73. So, the cluster of data points over on the
25 right-hand side between 45 and 60 degrees Celsius,

1 those all correspond to roughly 60 psi.

2 DR. BOWER: Thank you.

3 DR. SHEPHERD: At this point, I'd like to
4 summarize our findings from our laboratory testing.

5 Fifty gallons is sufficient to create a
6 flammable mixture in the center wing tank. You will
7 hear more about this later on, but from our preliminary
8 evaluations of weathered fuel, the weathering did not
9 eliminate the flammability. It's quite clear from
10 previous work on flight testing that the high
11 temperatures in the tank drive evaporation, and the
12 mixing within the tank - this is an important point
13 that we will hear a little bit more about - the
14 ignition energy is greatly reduced due to high
15 temperatures in the tank.

16 And finally, the explosion produces
17 sufficient pressure to create the observed damage to
18 the center wing tank structure.

19 Thank you, Mr. Chairman.

20 CHAIRMAN HALL: Thank you.

21 I think at this point, we need to take a
22 break. I assume there are other presentations;
23 correct?

24 DR. BOWER: Yes. We have very short
25 presentations . Then we go back to Dr. Shepherd on the

1 quarter scale results.

2 CHAIRMAN HALL: Well, let's take a break
3 until 4 o'clock. We will reconvene at 4 o'clock.

4 We stand in recess.

5 (Whereupon, a brief recess was taken.)

6 CHAIRMAN HALL: We will reconvene this public
7 hearing.

8 We're in the discussion of the Flammability
9 Panel . We have just completed one presentation by Dr.
10 Joseph Shepherd at CAL Tech, and we have other
11 presentations by the members of the Panel to follow.

12 Dr. Birky, if you would make the necessary
13 introductions and lead us on.

14 MR. BIRKY: The next short presentation is by
15 Dr. John Sagebiel who will give us the findings on the
16 vapor sampling during the flight tests.

17 Dr. Sagebiel.

18

19 Presentation By

20 DR. JOHN SAGEBIEL

21

22 DR. SAGEBIEL: Thank you, Dr. Birky. Good
23 afternoon, Mr. Chairman, Members of the Board.

24 CHAIRMAN HALL: Dr. Sagebiel, I will have to
25 ask you, as others, please bring your microphone close

1 and speak into it clearly. Thank you.

2 DR. SAGEBIEL: Yes, sir.

3 My involvement in this program was involved
4 with the flight tests that have already been described
5 this afternoon by Dr. Daniel Bower, and exactly what I
6 was doing is on this title slide here, the sampling and
7 analysis of the vapors from the center wing tank of our
8 test Boeing 747-100 series aircraft.

9 I think it's important to mention here that
10 these were, as far as we are aware, the very first
11 samples ever taken from the ullage of an aircraft fuel
12 tank in flight, that is, as the plane was being
13 operated, as described earlier. This is important
14 because while we have experimental information about
15 the vapor pressure and flammability of the fuels, as
16 has been described just prior to my presentation, until
17 we actually took these samples and measured them, we
18 really didn't know exactly what was inside the tank.

19 What I would like to do then is very briefly
20 describe what happened and what we found. We
21 collected, as I have said, and has been described on
22 the animation of Dr. Bower, that vapor samples were
23 collected from the center wing tank during test
24 flights. I returned these samples to my laboratory in
25 Reno, Nevada, and analyzed them for fuel vapor

1 components by gas chromatography, and those results
2 then were compared to the fuel ignition data, much of
3 which you have just seen in the prior presentation.

4 Again, as already described from the flight
5 test animation, there were three samples per-flight.
6 There were three flights on which we collected vapor
7 samples. The three samples in each flight were one at
8 taxi, one at 10,000 feet approximately during the
9 climb, and one at 10,000 feet approximately during the
10 climb of the aircraft.

11 This figure describes briefly the flight
12 operation sequence, and I think it is important to
13 describe this from the standpoint of what has been
14 discussed as weathering or changing of the fuel. The
15 zero time here along the X axis, this is elapsed time
16 from fueling. This was when a small amount of fuel, as
17 described by Dr. Bower, added to the center wing tank
18 of the test aircraft.

19 The vertical axis simply shows the altitude
20 at which the aircraft reached during each of the test
21 flights. The first flight went to less than 20,000
22 feet. There was a gap in time. The first vapor sample
23 flight, indicated here by this red arrow, took place
24 about 28 hours after the tank was fuel. The second
25 vapor sample flight here by this red arrow, which was

1 the TWA emulation flight, took place about 35 hours
2 after fueling, and the third vapor sample flight, which
3 is indicated by this arrow here, was in excess of 60
4 hours, and the described flight excursions from the
5 point at which the fresh fuel, or relatively fresh
6 fuel, was added to the center wing tank.

7 I would like one more time, just for clarity,
8 to describe the terminology that we're using here. We
9 talk about, and Dr. Shepherd talked about a fuel-to-air
10 mass ratio. This is simply the mass of fuel vapor
11 divided by the mass of air that's found at any given
12 point at any location that you want to measure.

13 A fuel-air ratio is analogous - I use the
14 analogy here - to a rich-versus-lean operation of a
15 car's engine. Those of you who have ever tuned your
16 own car when cars had carburetors and fuel air
17 adjustments, you could run the car rich, or you could
18 run the car lean, and there are points, as was
19 described earlier, under each of those where the fuel
20 is too rich to burn or too lean to burn.

21 As also described, air has weight. Air
22 weighs about 1-1/4 ounces per-cubic foot at the sea
23 level, and it weights less at higher altitudes. The
24 reason for this is described in this last bullet point
25 is that air gets thinner at higher altitudes. With

1 less pressure on the air, molecules are literally
2 spaced farther apart. So, therefore, a mass of the
3 given volume of the air is less.

4 The key findings that I'd like to discuss of
5 my sampling and analysis program were that the fuel:air
6 ratios increased with altitude and are flammable at
7 14,000 feet at that sample level, but are near or below
8 the flammability at the sea level at the taxi samples
9 where the flights began.

10 Fuel weathering, that is, changing the
11 composition and therefore changing the physical
12 properties of the fuel, did occur during the test
13 flights. Even after 60 hours of flight operations
14 indicated on that previous graph, the fuel vapors were
15 in the flammable range at 14,000 feet.

16 This figure then describes these key
17 findings. Briefly here across the bottom axis
18 indicated by the pointer, is the fuel-to-air mass
19 ratio, and on the vertical axis is the altitude that
20 the aircraft was at when the sample was taken.

21 The three flights are indicated as three
22 different lines connecting three different points, the
23 lowest three points here being at taxi, the middle
24 three points here being at 10,000 feet, and the top
25 three points here being samples taken at 14,000 feet.

1 I used for an example down here, the TWA 800
2 emulation flight, which has been discussed by Dr.
3 Bower. As the plane climbed, you can see here,
4 clearly, by the time it reached 14,000 feet, was up in
5 the flammable range.

6 Now, what do I mean by that? This vertical
7 black line at .03 fuel-to-air mass ratio is a guideline
8 for the lower flammability limit of the fuel. The
9 reason that the colors here are shaded in this region,
10 going from blue to red, is that that is not a strict
11 line . It is dependent upon other conditions, including
12 the temperature and the energy of the ignition source,
13 as has been described.

14 The temperatures that we observed here in the
15 tank ullage, which was also reported by Dr. Bower, were
16 between approximately 100 and 112 degrees Fahrenheit
17 here at the highest altitudes, and somewhat higher
18 between 100 and 123 degrees Fahrenheit for these
19 samples at the taxi, or at sea level elevation.

20 The last feature I'd like to point out from
21 this figure is this point here, the triangular point,
22 and that is, the vapor sample from the third flight
23 that we took vapor samples from on the 16th of July, as
24 indicated in my graph that showed the excursions of the
25 aircraft, this sample here was taken after 60 hours of

1 flight operations, and the fuel had weathered. We did
2 measure weathering of the fuel, and yet, it was still
3 able to reach a fuel-air mass ratio in the tank under
4 these flying conditions that was in the flammable
5 range.

6 The significance of these findings, in my
7 opinion, are clearly that the center wing tank ullage
8 was flammable at 14,000 feet. I would also like to
9 restate that these are the first samples of tank ullage
10 that we know of that I'm aware of, that were taken
11 during actual aircraft flight operations, and they do
12 provide, therefor, the experimental verification that I
13 feel is necessary for determining that the fuel, the
14 properties of which can be studied in a laboratory,
15 that those properties will actually result in a
16 flammable fuel air mixture inside the tank during
17 flight operations.

18 This work is tied very closely to the other
19 work that's going on. As I said, this covers the
20 actual fuel tank samples, vapor ullage samples, taken
21 during the test flights in July of 1997. The results
22 are similar to vapor pressure measurements, and I
23 believe we've got a presentation on that coming up.
24 And the understanding of the risk of the fuel air
25 mixtures that we measured and found in the tank

1 requires a knowledge of the fuel properties that are
2 determined in the flammability testing, specifically,
3 the ignition properties.

4 That concludes my presentation of the key
5 findings of my work.

6 Dr. Birky?

7 MR. BIRKY: Thank you.

8 Before we go into Jim Woodrow's presentation,
9 I'd like to just make sure we put on the record that
10 this fuel that we're talking about in that center tank
11 for the simulation flights was fuel from Athens,
12 Greece. Roughly the same flash point of that was on
13 the TWA accident. So, I'm not sure that was on the
14 record.

15 Mr. Woodrow, would you please cover very
16 briefly your measurements in this flight test?

17

18 Presentation By

19 JIM WOODROW

20

21 MR. WOODROW: Thank you, Merritt.

22 Good afternoon, Mr. Chairman, Members Of the
23 Board, and Ladies and Gentlemen.

24 May I have the first slide, please?

25 (Slide)

1 MR. WOODROW: As you can see from the title,
2 my contribution to the investigation involved making
3 laboratory measurements of the vapor behavior of jet
4 fuel under center wing tank conditions, or simulated
5 conditions .

6 Next slide, please.

7 (Slide)

8 MR. WOODROW: I would just like to take a
9 minute or so and talk about the weathering. This graph
10 is a bar graph. It looks rather complicated, but it's
11 a graph of subsection carbon number versus relative
12 concentration of vapor for the liquid fuel samples that
13 were taken during the test flights that have already
14 been discussed. Here, they are numbered 1 through 7.

15 Number 1 was the initial preflight sample
16 that was taken. The fuel was taken out of an outboard
17 wing tank, I understand, after it had flown in from
18 Athens, and then loaded into the center wing tank of
19 the 747.

20 Now, if you just move to the chromatogram, I
21 will explain those subsection carbon numbers. This is
22 a gas chromatogram of jet fuel vapor. As you can see,
23 it's a complex mixture of hydrocarbons. Really, what I
24 want us to focus on, the numbers down below; I divided
25 that chromatogram into eight subsections, each one of

1 which is characterized by a particular carbon number
2 from C-5 to C-12, in other words, from Pentane to
3 Dodecane.

4 During the test flights when the fuel
5 underwent weathering, what happened is, that the
6 lighter components from about C-5 up to about C-9 were
7 lost in preference to the heavier compounds. The fuel
8 vented out of the tank, but the lighter components were
9 lost to a greater percentage than the heavier
10 components. so, the fuel became enriched in the
11 heavier components.

12 Let's go back to the previous slide, and I'll
13 show you what I mean by that.

14 (Slide)

15 MR. WOODROW: SO, if you look closely at this
16 bar graph, I just mainly wanted to point out that when
17 you look at the test flight samples, the solid black
18 bar is, again, the preflight sample. The subsequent
19 bars show for those subsections, or carbon numbers less
20 than 9, you can see a definite decline in the relative
21 concentration of the vapor with successive flights. So
22 you can see that the fuel was depleted in lighter
23 components.

24 But if you go to about C-9 and above C-9, you
25 can see a relative increase in the heavier components

1 in the vapor. This is what we mean by weathering of
2 the fuel.

3 Let's go to the -- okay.

4 (Slide)

5 MR. WOODROW: I want to cut to the chase here
6 and just show you the results of measuring the vapor
7 concentration of these test flight samples. This is a
8 plot that is similar to the one that Dr. Sagebiel
9 showed. It is a plot of fuel:air mass ratio against a
10 fuel temperature and degrees Fahrenheit, and again, the
11 fuel:air mass ratio is just simply the mass of fuel
12 vapor divided by the mass of air containing that fuel.

13 I show on this plot on the extreme right line
14 is an example of what unweathered fuel had looked like.
15 This is at 14,000 feet, by the way. All the lines that
16 are clustered together are made up by the test flight
17 samples 1 through 7 showing they are clustered. The
18 vertical line at .03 fuel:to air mass ratio is a lower
19 flammability limit, and I agree with Sagebiel, it is
20 not really a hard and fast line of demarcation; it's a
21 blurred area.

22 But I have it here as a reference point
23 mainly to show that although compared to the
24 unweathered fuel, the test flight fuels underwent
25 weathering; it's very obvious. They still were

1 flammable at 14,000 feet, and at temperatures ranging
2 from a little over 105 degrees up to 140 degrees of the
3 test temperatures.

4 I tried to reproduce the temperatures in the
5 lab that were observed in the aircraft.

6 (Slide)

7 MR. WOODROW: The next slide just shows some
8 of the same data, a comparison between 14,000 feet and
9 sea level. You can see how important it is, not only
10 the temperature, but have the fuel at altitude and the
11 fuel actually is flammable at a lower temperature at
12 14,000 feet.

13 Next slide, please.

14 (Slide)

15 MR. WOODROW: So just briefly, summarizing
16 the findings, we observed the fact that jet fuel
17 exposed to flight conditions showed weathering effects,
18 or what we call differential volatilization compared to
19 unweathered fuel, and the weathering occurred in a
20 characteristic way, preferential losses of the lighter
21 components, and accumulation of the heavier components.

22 This resulted in an overall lowered vapor
23 pressure for the fuel totally, showing an increased
24 average molecular weight. But despite these
25 compositional changes, weathered jet fuel is still

1 flammable at 14,000 feet, and that temperature is
2 greater than about 104 degrees Fahrenheit.

3 (Slide)

4 MR. WOODROW: Then the last slide, Dr.
5 Sagebiel mentioned -- I'm sure there is a slide of his
6 vapor samples. I just wanted to make a comparison
7 here, showing how the laboratory measurements stacked
8 up against the measurements made by John, and this
9 slide shows that, again, for fuel to air mass ratios
10 plotted against altitude and feet.

11 The liquid test samples went through seven,
12 and then vapor flight samples, 1 through 3, and the
13 extreme right line represents the preflight, the
14 initial preflight sample. As you look to the left, you
15 notice how all the various samples cluster. We don't
16 need to look at the individual lines, but the point
17 here is, they all cluster together.

18 I used my 122 degree Fahrenheit data for the
19 laboratory compared to John's test flight, vapor
20 samples, and they compare very well, indicating that
21 the laboratory simulation is very reliable.

22 That's all I have to present at this time.

23 Dr. Birky.

24 MR. BIRKY: Thank you.

25 I think we will go on to the quarter scale

1 measurement so we get them on the record, as well as
2 then go on into the modeling, and we will then go back
3 and ask questions later on.

4 So, Dr. Shepherd, would you go ahead with the
5 quarter scale work.

6
7 Presentation By

8 DR. JOSEPH SHEPHERD

9
10 DR. SHEPHERD: Thank you, Dr. Birky.

11 I would now like to present our program that
12 we carried out on scale model testing of explosions
13 inside the center wing tank. This work has been a
14 cooperative venture between our laboratory, Applied
15 Research Associates, Rocky Mountain Division in Denver,
16 Colorado, and the Safety Board.

17 There has been a large number of individuals
18 involved in this effort. In addition, down at the end
19 of the table here, the modelers have had a significant
20 contribution to that, also, I would like to
21 acknowledge.

22 Let's turn that off.

23 Okay. Why did we carry out quarter scale
24 model tests? We wanted to examine combustion issue
25 which were not addressed in our laboratory testing.

1 Laboratory testing was done in small vessels, simple
2 design, simple construction. When we wanted to look at
3 some other issues, I would like to point out, first of
4 all, in our testing, we have used a simulant fuel
5 instead of Jet A. This was done for a number of
6 reasons, which we can touch on a little later on in the
7 questioning period.

8 We have planned a series of about 30 tests.
9 They are now about 90 percent complete. We have made a
10 number of photographic and electronic measurements in
11 these tests, and we are making comparisons with what we
12 see in laboratory test computations and wreckage from
13 the crash.

14 I would just like to point out some of the
15 things that we think are important about the modeling
16 tank. First of all, we need to include all of the
17 beams and the spars of the tank, partial ribs. The
18 water bottles in the front are important from a
19 structural point of view.

20 You recall that the first bay is a dry bay,
21 and it is not filled with fuel, or will not contain a
22 fuel air mixture. And in addition, we have a venting
23 system, which is, again, indicated schematically, and
24 it's not strictly speaking, correct.

25 And finally, in the examination of the

1 wreckage, it was found that there was a manufacturing
2 access panel and spanwise beam 2 that appeared to have
3 been ejected early on in the accident, and the failure
4 of that, we felt, was important to the model.

5 What does our scale model look like? Well,
6 this is an attempt to convey a sense of the size. It
7 is one-quarter scale geometrically, that is, every
8 dimension has been scaled down. We have not preserved
9 all the features. Here is a list of some of the things
10 that we have had to include in order to do this
11 experiment.

12 We have transparent sides on the tank. We
13 have transparent partial ribs. That's so that we can
14 see through the tank and have a visualization of the
15 propagation of the flames, and we are able to adjust
16 the strength of the beams and spars to examine the
17 effect of failure on the combustion.

18 This is what the actual test fixture looks
19 like. It's constructed of heavy steel so that we can
20 re-use it and do a number of tests.

21 The key idea here is, this is an engineering
22 scale model; it's not a scale model in the sense of a
23 plastic model that you buy and put together that
24 resembles a car or a plane. The key thing here is that
25 the dimensions are scaled appropriately. The linear

1 dimensions are one-quarter scale of the full values.
2 The areas are one-sixteenth, and the volumes are one-
3 sixty-fourth.

4 The flames speed and the maximum pressure
5 will be the same as in the full-scale values. The
6 event, however, will happen in one-quarter of the time
7 required for a full-scale event. The most important
8 aspect of our scaling is that we expect a sequence of
9 events, the pressures and the gas motion to be
10 replicated in the scale model for a given ignition
11 location.

12 And now, we'd like to show the video. Here
13 are some of the things that we felt were important to
14 reproduce: the geometrical proportions, the flow areas
15 corresponding to the various openings between the bays
16 and the tanks; the volumes of all the bays; the amount
17 of fuel vapor. We chose as a standard condition the
18 amount of fuel vapor that you would have at a
19 temperature of 50 C., and most importantly, we also
20 wanted to model the altitude effect.

21 We used a scaled amount of liquid fuel in
22 some of the tests corresponding to the 50 gallons in
23 the center wing tank, and a test in which we had weak
24 beams and spars, that is, those partitions failed and
25 were ejected from the tank. We scaled a mass of those

1 and the water bottles.

2 The parameters that we varied in our test
3 have been the number of bays that was done in order to
4 provide the information that's important for our
5 validating the combustion models. The operation of the
6 vent tubes and the stringers, that's to investigate the
7 role of venting during the combustion, the strength of
8 the beams as spars, this is not designed to study the
9 actual failure process, but, rather, to understand the
10 effect of the failure process on the combustion.

11 In addition, we have varies the vapor fuel
12 amount, the presence of the liquid layer, and most
13 importantly, the ignition location.

14 We have done four series of tests. the Alpha
15 series, we had no venting. We used all strong beams
16 and spars. Beta series, we used venting, all strong
17 and varied ignition location; and the gamma series was
18 vented. We had weak beams and spars. That means that
19 they all would fail when the pressure reached about 20
20 psi. We varied the ignition location, and we also
21 added liquid fuel in some of those tests.

22 Finally, we have done a configuration which
23 we call part strong, which corresponds to best estimate
24 of the failure of sequence, as determined by the
25 sequencing analysis group, and the crash investigation

1 that corresponds to failure of front's bar, spanwise
2 beam 3, and the manufacturing access panel.

3 We varied the ignition location and the
4 amount of liquid fuel, vapor fuel amount, and we
5 planned to look at venting into a model forward cargo
6 department.

7 At this point, I would like to show you a
8 video of some of our tests that we've done. This video
9 is going to show a description of the quarter scale
10 facility, and then it's going to show the results from
11 two tests, Test Number 4, which consists of all the all
12 strong configuration with ignition, and what we're
13 calling Bay 5 in Test 21, which was an all weak case
14 with ignition in Bay 2 and liquid fuel.

15 First, I'd like to illustrate what I mean by
16 the number of bays, and so this is our schematic. The
17 numbering roughly corresponds to the numbering that Dr.
18 Bower used in his explanation. We see that Bay 1 is in
19 between spanwise beam 3, and spanwise beam 2. Bay 2 is
20 between spanwise beam 2 in the midst bar, and so on.
21 The ignition in Test 4 was carried out in Bay 5, which
22 is the left aft bay.

23 The other tests that we're going to be seeing
24 is Test 21. The ignition in that case was carried out
25 in Bay 1 in all of the features, the partial ribs,

1 spanwise beam 1, missed bar, spanwise beam 2, spanwise
2 beam 3 and the front bars are weak structures that will
3 fail around 20 psi. This test also contained liquid
4 fuel between the bar and spanwise beam 3.

5 (Whereupon, a video was played.)

6 DR. SHEPHERD: That concludes this portion of
7 the presentation, Merritt.

8 MR. BIRKY: Joe, did you have any final
9 comments that you would like to make on that series of
10 tests in terms of any conclusions you'd like to make on
11 that?

12 DR. SHEPHERD: Yes, I have some concluding
13 remarks that I could make at this time, Merritt.

14 I think the most important aspect of our
15 testing is that we have found that combustion occurs in
16 a complex fashion within a center wing tank, but in all
17 cases, the pressure within the tank increases quickly,
18 once the flame has propagated through the bay in which
19 ignition has occurred.

20 The beams and spars in the front of the tank
21 failed and ejected immediately after the failure
22 pressure was reached. This behavior is, of course,
23 sensitive to the amount of fuel vapor, and we are
24 continuing testing on this aspect; another problem.

25 A fire ball is produced when spanwise beam 3

1 and the front spar fail. This could produce an
2 increase in pressure within the fuselage, and again,
3 testing on this aspect of the problem is in progress.

4 It appears that the damage observed in the
5 crash wreckage could have been produced by ignition in
6 any of the bays. Our testing has been designed to
7 examine specific features of the explosion that might
8 be produced by various ignition locations, and that
9 testing is still in progress.

10 MR. BIRKY: I'd like to ask just one
11 question, and then we will move on, I think, to the
12 modeling effort of it.

13 I want to make sure we clarify this question
14 of simulant fuel so that people understand that Jet A
15 was not used in this test, except for the liquid fuel.
16 Would you comment on that a little bit, Joe?

17 DR. SHEPHERD: Yes. If we could have my
18 computer screen back, I can show you what we did in
19 order to simulate the Jet A. There are a number of
20 problems trying to do a heated experiment at a lower
21 pressure than ambient, and for that reason, we chose to
22 find a combination of fuels. In this case, it was a
23 mixture of propane and hydrogen.

24 We adjusted that combination of fuels to
25 match the pressurized and flame speed in Jet A that

1 would be created from the liquid layer scale to 50
2 gallons in the center wing tank at 50 degrees C.

3 This graph shows the results of experiments
4 that we did in our laboratory at CAL Tech in our 1,100
5 leader vessel. You see the red line represents the
6 results from testing with Jet A at pressure of 6/10 of
7 an atmosphere, and the blue line is the results of
8 doing testing with a pressure of about 8/10 of an
9 atmosphere, which is what we have at Denver at the test
10 site with our simulant.

11 The simulant and the jet fuel are fairly
12 closely matched, and more importantly, the initial
13 development of the flame, which is measured by the
14 flame's speed, is matched precisely.

15 MR. BIRKY: And this is done at 14,000 feet
16 equivalent?

17 DR. SHEPHERD: Yes.

18 MR. BIRKY: I'm sure there are a lot of
19 questions, but I would like to get into the quarter
20 scale modeling at this point, if I could.

21 For that inquiry, I am going to turn it over
22 to Mr. Dennis Crider for starting that part of the
23 program.

24 MR. CRIDER: Thank you, Dr. Birky.

25

1 Presentation By

2 DENNIS CRIDER

3

4 MR. CRIDER: Good evening, Mr. Chairman,
5 Ladies and Gentlemen.

6 CHAIRMAN HALL: You've got to get closer to
7 the microphone, please.

8 MR. CRIDER: Yes, sir.

9 Good afternoon, Mr. Chairman, Ladies and
10 Gentlemen.

11 I'd like to start off this series of
12 questions on computer simulation with a series of
13 questions to Dr. Paul Thibault.

14 CHAIRMAN HALL: Now, we've completed all our
15 presentations; is that correct, Mr. Birky, or not?

16 MR. BIRKY: Yes. We have completed the
17 presentations at this point. We have not completed
18 the questions about some of the issues on the
19 experimental testing yet.

20 CHAIRMAN HALL: I have some questions, but
21 I'll wait until we get all the presentations and
22 questions done.

23 MR. CRIDER: Dr. Thibault, what is computer
24 modeling?

25 DR. THIBAUT: If you could show the first

1 slide.

2 (Slide)

3 DR. THIBAUT: I'm going to try and explain
4 that in most simple terms. Computer modeling is a
5 method that is used for a live variety of applications
6 since the development of computers obviously.
7 Basically, if you have a problem, whether it's an
8 explosion or any other type of problem, you need to be
9 able to come up with some physical laws to describe the
10 processes for this problem.

11 Physical laws. Well, what are physical laws?
12 Newton's law of gravity would be a physical law.
13 Einstein's theory of relativity is a physical law. How
14 do you get these physical laws? Often by experiments.
15 If you are as smart as Einstein, you don't need
16 experiments . You just come up with a theory and let the
17 experimentalists prove it.

18 Most of us at this table are relying - at
19 least at this corner - on experiments. But you come up
20 with these physical laws. These physical laws is for
21 who comes up with them, they are typically engineers
22 and scientists, and the first thing they do is to write
23 these laws in the form of equations. This is really
24 their working tools.

25 Now, if the problem is simple, you can take

1 those equations and just solve them on a piece of paper
2 and you've got the answer. If it's more complicated -
3 and certainly, this problem here falls in a much more
4 complicated category - that will not work easily, and
5 you will need the computer to solve the equations.

6 MR. CRIDER: How do you go about computer
7 modeling in this case?

8 DR. THIBAUT: Well, as we know from
9 experience, computers are powerful, but not very smart.
10 We need to tell them how to solve these equations.
11 They don't really know what we're giving them; they
12 just know that they've got to solve them, and we give
13 them a recipe to solve them.

14 so, we have a group, often mathematicians,
15 that come up with methods of solving these equations,
16 and they develop what we call numerical methods. These
17 are numerical because we're talking about numbers, and
18 they develop methods how to crunch the numbers in the
19 computer.

20 Once the computer gets these instructions,
21 solves the problem, puts out an output in the form of
22 numbers, graphs, and often in computer animations.

23 If you show the next slide, I will kind of go
24 over quickly how that gets done for explosion modeling.

25 (Slide)

1 DR. THIBAUT: Explosion modeling certainly
2 falls in the category of multi disciplinary modeling,
3 and therefore, quite a wide group of scientists are
4 involved. An explosion basically involves combustion.
5 It generates flow, and if the vessel or whatever
6 structure is weak, then you get damage.

7 Usually, you're interested in explosions
8 because there was damage, so usually for accident
9 analysis, all these three aspects come into play.

10 The combustion part, well, all you really
11 need to know about it is that to understand it is that
12 you start with a group of molecules, let's say,
13 hydrogen, oxygen, or in this case, we had fuel and air.
14 You break up the molecules. That's usually done by the
15 ignition source, and then these molecules break up and
16 re-form into new molecules usually water and CO₂,
17 carbon dioxide.

18 What's important as far as what happens to
19 the structure is the energy that is put out when these
20 new molecules are formed. This energy goes into the
21 flame, and as the flame travels, as it is liberating
22 energy right at the flame front, it is heating up the
23 gas, and because it's heating up the gas, it expands
24 the gas, and because it's expanding the gas, it pushes
25 the unburned gas ahead of it and makes that gas flow.

1 If there happens to be an orifice, an
2 obstacle, or even if you're in a closed room, you're
3 going to form a very complicated flow when that
4 happens. The modeling of flow, just so you can
5 understand some of the terminology we're going to use
6 here, is usually called fluid dynamics.

7 The word "fluid" comes because we're modeling
8 flows . Gases and liquids are considered fluids because
9 they flow, and that's pretty much it. And they can
10 flow into very complicated structures with low pressure
11 zones pretty similar to when you wake up in the morning
12 and look at your satellite weather picture in hurricane
13 season, and you see all the water seas; that's fluid
14 dynamics.

15 Now, why we call it dynamics? It's because
16 it's changing with times, therefore, the word dynamics.
17 SO, we've got fluid dynamics. In this case we are
18 changing over days or changing over milliseconds.

19 Now, the other important effect of the flame
20 as it releases energy and causes this gas expansion, is
21 that it produces pressure. Of course, that's what the
22 structure is vulnerable to, is the pressure that's
23 generated.

24 Structures are usually made out of solids,
25 such as metals, and metals, solids, usually do not

1 flow. so, they tended to form and break, and we need
2 another group of models to handle them. Since we call
3 them solids, then we usually call the fuel that we look
4 at, the deformation and fracture of solids is usually
5 called solid mechanics.

6 These are the three main ingredients that we
7 need to look at for the model.

8 If you go into the next slide.

9 (Slide.)

10 DR. THIBAUT: How do you go and put this on
11 a computer? I basically described some of the
12 phenomena in very simple terms here, but we need to put
13 this into the computer. We have three areas that we
14 need to consider here: The combustion, obviously,
15 which is the source of all this; the fluid dynamics,
16 because of the flow that is produced; and the solid
17 mechanics because we are wondering what's going to
18 happen to the structure, or understand what's happening
19 to the structure.

20 Again now, we've got to put all these laws of
21 these three different disciplines into a computer.
22 Pretty much what we do is, again, we go to numerical
23 methods. People come up with basically numerical
24 recipes to put these equations -- and these equations
25 are now getting quite complex. Each one of these

1 fields have quite a long list of equations. And you
2 want to be able to put those in the computer.

3 If you combine fluid dynamics and numerical
4 methods, in other words, that the scientist engineers
5 and the mathematicians got together and they're going
6 to put this into the computer, they're going to come up
7 with a discipline that we call computation fluid
8 dynamics, CFD.

9 CFD is a field which pretty much started as
10 computers came out, but I think people have heard more
11 about it since, I would say, from the mid-Seventies
12 when computers got particularly useful to people, and
13 the algorithms, let's try a numerical recipe; got
14 sophisticated enough that we could put these on a
15 computer, and it would give us an answer that is useful
16 to us.

17 **so**, what we're going to talk about modeling
18 is going to be computational fluid dynamics. What I
19 said is all you really need to know to understand what
20 it's trying to do. We will get into it a bit later on
21 with other people, exactly how that's done.

22 Solid mechanics is the same thing. Combine
23 solid mechanics and numerical methods, and you come up
24 with a term that's called computational solid
25 mechanics, CSM. You take those and you combine with

1 combustion, and you got yourself a program otherwise
2 known as a code, otherwise known as most of us
3 understand it, as software.

4 Take that software, put it in the computer,
5 and you get results.

6 MR. CRIDER: Excellent. What are the
7 objectives in this case?

8 DR. THIBAUT: Well, as has been mentioned,
9 there is one primary objective, which is the third
10 bullet on this flight, the term possible ignition
11 location. There are other objectives before that,
12 though, as Dr. Shepherd mentioned, the modelers were to
13 derive some input into quarter scale experiments to get
14 an idea of what would kind of experiment would be
15 meaningful .

16 Now, we have to give credit to Dr. Shepherd
17 here. There wasn't much to be added. Most of it came
18 from his head without CFD, but there were some areas
19 which he will mention that the models did contribute
20 to.

21 Another important aspect of CFD and explosion
22 modeling, let's say, is to provide inside in the
23 physical processes. You can have an experiment. You
24 can make some measurements. You can have a bit of
25 visualization, but it might still be difficult to

1 figure out exactly what happened. Computer modeling
2 offers you some advantages there, but as far as this
3 group is concerned, the main objective was to determine
4 the ignition location in the accident.

5 MR. CRIDER: Are there some things that you
6 can do with computer modeling that would be difficult
7 to do experimentally?

8 DR. THIBAUT: I think where they differ is
9 more in the scope of the input and the output, and when
10 I say "input, " what we put into the computer model and
11 what we get out of it, the computer is incredibly
12 powerful generating data, and it's also not too picky
13 the data you put into it. As I said, the computer is
14 not that bright in that sense. You put in whatever you
15 want, and you get whatever you want. But it gives you
16 that flexibility. You can pretty much put in anything;
17 you can pretty much get out anything.

18 As far as the input, some of the work or some
19 damages, certainly the geometry, putting in different
20 geometries in an explosion model is relatively simple,
21 and certainly not very costly because you don't have to
22 manufacture anything.

23 I think another important aspect, though, is
24 the initial pressure. If you want to do, let's say, a
25 scale model on the center wing tank, you would have to

1 go to a certain elevation to get at the right pressure.
2 With computer models, we don't need to do that. We
3 just change the number and call it the initial
4 pressure, and we run the calculation.

5 We know from the flight test data that the
6 fuel concentration was not uniform in the tank. That
7 is one area where it is trivial for a computer model to
8 change that and to put in whatever sensible value that
9 might be.

10 We can change the ignition location, but to
11 be fair, it's just as easy to change ignition location
12 in an experiment, so that's not a big advantage.
13 Structural failure criteria, that is an important issue
14 here. The failure of the partitions was not a simple
15 process. The criteria for failure, there is a criteria
16 if a panel fails without the other panels failing, but
17 there is another criteria if an adjacent panel failed.

18 so, the criterias for failure can become
19 quite complex when you actually go in to analyze the
20 accident. That is something that the computer modeling
21 can help you.

22 Probably one of the most important benefit is
23 that you can go to a larger scale without any
24 additional cost. The computer doesn't care whether
25 you're modeling something that's 2 inches in

1 dimensions or 5 miles in dimensions. It doesn't care.
2 so, there is an advantage there.

3 On the output, the usual thing you get from
4 an experiment, you get pressure. In experiments, you
5 can also get temperature. There are other variables,
6 though, that become more difficult to get from an
7 experiment, flow velocity, for example; how fast the
8 flow is moving. How turbulent is the flow? Is
9 agitated is the flow? How unstable is it?

10 Also, the chemical composition during
11 combustion. So, those are some of the areas, as you go
12 down that list on the bullet, modeling can offer you
13 things that become more difficult for experiments.

14 MR. CRIDER: Well, as you said, the important
15 things, of course, is since you have to be very careful
16 on the coding, how do you go about validating the code
17 and the work in general?

18 DR. THIBAUT: Well, that's an important
19 issue. As I said, the problems with computers is that
20 they have no idea what you're putting into them, and
21 therefore, they will take anything and give you
22 answers. You have to validate these codes before you
23 use them for a practical application.

24 I'd like to answer that question in two ways:
25 There are different types of validation if you come up

1 with these laws and you come up with equations. Now,
2 you have to understand that any law or any equation you
3 write down, is an approximation. It's a human
4 description of what that human thinks is happening in
5 that physical process. That's all it is.

6 And the better we get at it, and the more
7 generations we go through, we get better answers.

8 MR. BIRKY: Paul, may I just interrupt you a
9 minute, and ask a question? What do you mean by
10 "validation?" To check with reality? Is that what a
11 validation is?

12 DR. THIBAUT: That's as good a definition as
13 I've heard, yes.

14 MR. BIRKY: Okay, thank you. Go ahead.

15 DR. THIBAUT: The first phase is validation
16 of the equations; in other words, of the equation
17 solver. This is where the numerical methods people,
18 those mathematicians, gave you these recipes to solve
19 your equations. You got the equations, and you want to
20 know that they're solving those equations properly.

21 There are different ways of doing that, and I
22 won't get into detail, but that's basically saying that
23 if I have these equations, am I solving them properly?
24 Now, this doesn't mean that you've got right answers.
25 This just means that you solved the equation you

1 thought were correct properly. This does not mean that
2 your equations were correct to start off with.

3 To understand whether the equations you start
4 off with were correct, you've got to go to the next
5 step and compare it with experiments. Even the
6 greatest had to go through that. No matter how
7 intelligent you are, nobody will believe you until you
8 have experimental validation, which means for you to
9 take a problem, calculate on a computer, and have
10 somebody, preferably independently, do an experiment.

11 Another way is to compare with other codes,
12 programs, software, that try and model the same thing.
13 This is very important because different programs may
14 use different models, or maybe are more accurate for
15 the models that they're using. So, that adds an
16 additional check and balance.

17 You have to accept that when you go through
18 this type of method, both experimental and
19 calculations, you never take for granted that the
20 results you're getting are totally correct.

21 No experiment is perfect, and no calculation
22 is perfect. The more that you try and compare between
23 models and experiments, the greater level of confidence
24 you have that you're getting the correct answers. Once
25 you've gone through that stage, then you want to go to

1 the right column there which is the validation stages.
2 There are two ways of validating by comparing with
3 experiments .

4 I mentioned fluid dynamics; I mentioned
5 computational solid mechanics; I mentioned combustion.
6 And each one of those, these are large disciplines, and
7 each one of those, there are many submodels. You want
8 to check each one of those individually to make sure
9 that each one of those is correct because you could
10 have lots of models and get the right answer for the
11 wrong reasons.

12 so, you must check that each model is
13 correct, the submodels. That's usually done with small
14 scale experiments quite similar to what was done at CAL
15 Tech in their laboratory, looking at the burning
16 properties of the fuel. Once you are confident that
17 your submodel is correct, then you can go into a
18 validation exercise for a small scale geometry, and if
19 you did all right there, then you can proceed to the
20 full scale geometry.

21 MR. CRIDER: Okay. Excellent. Thank you,
22 Dr. Thibault.

23 I now have a couple of questions for Dr. Kees
24 Van Win Gerden. If you would, sir, could you describe
25 the physical processes that must be included to model

1 this problem?

2 DR. VAN WIN GERDEN: Yes, okay, I'd love to.

3 Mr. Chairman, I've seen that many people have
4 problems with my surname, so if somebody wants to
5 address a question to me, they can easily call me
6 "Kees," which is my first name. It's probably easier,
7 or "Kees," if you pronounce it in the American way.

8 What I would like to do is, I would like to
9 go back a little bit and go into the phenomena again to
10 answer this question, Mr. Crider.

11 My first slide.

12 (Slide)

13 DR. VAN WIN GERDEN: Yes. Thank you.

14 so, the problem of a gas explosion is that
15 the combustion creates combustion products, and they
16 are hot, and if something is hot, it will try to
17 expand, as you all probably know. Also, when you feel
18 hot, you want to expand. You want some space. The
19 same accounts for combustion problems. They will
20 expand.

21 If you try to hamper that, or try to limit
22 that expansion, you will get pressure build up. So,
23 the gas explosion problem is causing pressure. This
24 pressure is a result of the rate of generation of
25 combustion products, which is, in fact, the rate of

1 combustion, or the burning speed; and on the other
2 hand, how fast can you get rid of those combustion
3 products, or any gas in your room while the explosion
4 is occurring.

5 so, that will cause the final over pressure,
6 those two contracting factors.

7 The rate of generation of combustion products
8 is determined by what sort of gas do you have? What
9 sort of reactivity has this gas? How fast does it
10 burn? And it also depends on what is the concentration
11 of this gas in your gasometer. So, if you have a very
12 low concentration of gases, it may even be possible
13 that it is not flammable. It cannot burn, or if you
14 have too much, it might also be possible that it
15 doesn't burn.

16 In between those two ends, there is an area
17 where it can burn, and it will burn, depending on the
18 concentration. It will not burn everywhere as fast, If
19 the concentration is fast, as you may think that it
20 does.

21 There are also other factors as we mentioned
22 that have been very important. I will come back to
23 that.

24 On the other hand, the pressure is also
25 determined by the degree of confinement. If you have

1 an explosion in the open air, generally, you will
2 generate hardly any pressure. You will only hear some
3 sort of a puff, or whatever sounds you want to make.
4 It's not a bang.

5 SO, if I can go to my next slide where you
6 see the two limits.

7 (Slide)

8 DR. THIBAUT: You have a mixture of masse
9 and air, not Jet A, but masse and air, typical pressure
10 you will get in a closed bomb because of this expansion
11 which you in fact hamper. You do not allow it to
12 expand; you try to keep it together. So, in a closed
13 bomb, as you can see on the top side, you will get an
14 over-pressure of typically on the order of eight bars,
15 which is 8 times 15 psi; you know exactly how that is.

16 On the other hand, if you just allow it to
17 expand, you will get an increase of volume by a factor
18 of approximately 8. It means that you needed space by
19 approximately a factor of 8. That means that something
20 else had to vanish that was the air which was
21 originally there. It had to be pushed away, or, in
22 fact, the mixture which is there.

23 SO, those are the two limits. At one end,
24 you have a closed vessel which causes 8 bar, and on the
25 other hand, you have something which is no pressure,

1 but just a volume expansion.

2 Go to the next slide.

3 (Slide)

4 DR. THIBAUT: There are some factors which
5 determine the combustion rate, and one of them is the
6 gas type. In the top right corner, you see a vessel
7 which is a in fact general, which is closed on all
8 sides. It's only open at the right side, and there are
9 some baffles inside it.

10 If you prepare a mixture of hydrogen and air
11 there, you get a typical pressure of about 8 bars.
12 although it is open, the pressure can be released. If
13 you do, you may test with methane or ethane or propane,
14 you get much lower pressures, which are in the order of
15 perhaps tenths of a bar or two-tenths of a bar, much
16 lower. So, this is the gas type.

17 These mixtures which are shown here are
18 optimal. That means they are the fastest burning
19 mixtures you can prepare with hydrogen and air, or with
20 methane and air, or whatever is shown on this graph.
21 This concentration dependency is shown on the next
22 graph, experiments which were done in the same vessel.

23 Could you please show me the next slide.

24 (Slide)

25 DR. THIBAUT: Thank you. This slide shows

1 how the over-pressure in the same vessel would vary
2 with the concentration. So, only at one concentration,
3 which is the optimal concentration which in our terms,
4 is called a stoichiometric concentration. They will get
5 the pressure, which is the maximum for this particular
6 one for about half-a-bar.

7 But if you move away from that concentration,
8 you get lower pressures. So that has to be modeled, as
9 well, by your combustion code, or your code which
10 handles this kind of problem, this gas explosion
11 problem.

12 Please move on to the next slide.

13 (Slide)

14 DR. THIBAUT: We are running into this other
15 combustion rate increasing factors, which is
16 turbulence, a very important one, and there is also
17 something called combustion instability; but I don't to
18 go into that. But Turbulence is very important. In
19 fact, turbulence has been already shown and mentioned
20 by others.

21 It is generated by the explosion itself, and
22 I want to go briefly into that process so that you
23 clearly understand what is going on, and how
24 complicated this process is.

25 My next slide will show you what is happening

1 when you have turbulence.

2 (Slide)

3 DR. THIBAUT: Turbulence is a tornado, or
4 maybe generated by the flame itself. It is mixing of
5 air, like in a river. It is a mixer, and what it does
6 is, it mixes the unburned gas with the burned gas, or
7 it causes perturbations on the flame surface. That's
8 on the left side, or the mixing is shown on the right
9 side.

10 What you effectively are doing is, you
11 increase the surface area of the flame enormously, and
12 it burns much, much faster. So, it has to be modeled,
13 as well. So, how does a flame or a combustion wave
14 generate turbulence?

15 On my next slide, we will see a box, a
16 channel again, with some opticals.

17 (Slide)

18 DR. THIBAUT: This channel is closed on all
19 sides. It's only open at one end, which is on the
20 right end, so if you ignite a mixture, a flammable air
21 mixture in this box, you start a combustion. This
22 combustion is initially going very slow typically in
23 the order of half-a-second is the reaction speed. That
24 is the speed with which the flame eats itself through
25 the unburned gas. But it generates combustion

1 products, which are hot and want to expand. That
2 happens behind this reaction front, behind the flame.
3 They expand and they need a place.

4 If they need a place, something else is to
5 vanish, and that is the unburned gas ahead of the
6 flame. So you get a flow ahead of the flame. Well,
7 obstructions are shown here, these cylinders. You
8 will get these tornados, disturbance being generated.

9 As we saw, turbulence enhances the combustion
10 rate. It means it starts burning faster when the flame
11 gets there. That means that you generate more
12 combustion flow per-unit of time. They want to expand,
13 so they expand, and that means there is more expansion
14 for unit of time than there was before. That means it
15 needs more place and a flame, or the unburned gas ahead
16 of the flame will start flowing even faster.

17 **SO**, you get more intensive turbulence ahead
18 of the flame, as a new obstacle. When the flame gets
19 there, it starts moving or burning even faster. So, it
20 is in fact accelerating itself, and it goes faster and
21 faster.

22 On my next slide, you will see how this works
23 if you put it into a diagram.

24 (Slide)

25 DR. THIBAUT: So you've got combustion,

1 which is the block on the left side which causes an
2 expansion flow, as explained. This will cause
3 obstacles, as shown in this channel, turbulence, or at
4 the walls you can also get turbulence, or as you have
5 in the center wing tank through these passageways. You
6 generate turbulence at the passageways.

7 Due to that, the flame will start burning
8 faster gyrating through an expansion flow. You get
9 higher or more turbulence, et cetera, et cetera. So,
10 it's going through this loop all the time and it's
11 accelerating itself. So, as Dr. Shepherd showed,
12 initially, the flame burns very slowly, but once it
13 gets turbulent, it happens in no time. So, this is the
14 process we have to follow.

15 I have a video now which I would like to show
16 you . It just shows exactly what is going on, the
17 effect of an explosion in the channel. The first
18 pictures which are shown show a box, as shown in this
19 overhead of mine.

20 First, you will see that the box is empty.
21 There are no obstacles inside, and you see how the
22 flame will propagate through this box. So, there is
23 the box, and we ignite it from the left side of the
24 closed wall, and here the flame starts to burn, and
25 because of unburned gas being pushed out of the box

1 ahead of the flame, you get also that the flame can
2 move out of the box, as we also saw in his experiments,
3 especially the second one.

4 so, to use obstacles in this box, there you
5 get disturbed generation, and you will see that the
6 flame suddenly accelerates, and not only that, you get
7 also a violent explosion outside, because everything
8 now is very turbulent generated by the combustion
9 itself.

10 so, this is the kind of program we have to
11 model, though the same kind of process is in fact
12 happening in the center wing tank. So, he prepared the
13 two, which you see, a very strong difference between
14 the two. You see that the one without the turbulent
15 generation is going very slow, whereas, the one with
16 the obstacles and the low turbulent generation goes
17 very far.

18 It can even go one step further. It could
19 introduce some perforations in the top of the box. If
20 we do that, the combustion products do not expand only
21 in the direction of the obstacles any more, but they
22 can expand in fact up in the upward direction, as well.

23 Then we in fact tame the explosion
24 considerably, if you would be interested in that. So,
25 it is just to show how complicated an explosion is, and

1 how difficult it is to model that. So, here are the
2 perforations . You've got a flame which is now in fact
3 not propagating very fast any more.

4 The combustion probes can vent through the
5 top, and the turbulent flow fuel generated in the
6 direction of the obstacles, and with or without the
7 perforations in the top, you see that the one without
8 the perforations where the turbulence, in fact, the
9 turbulent flow is generated just in the direction of
10 the obstacles, you get a very violent explosion and
11 very high pressures because of that.

12 So you can also compare the three of them,
13 which is just to share with you once more. You see
14 the difference between the three. So, this is the kind
15 of complex processes that we are looking into.

16 Thank you very much.

17 **so**, if I could now just get my next and final
18 slide.

19 (Slide)

20 DR. THIBAUT: There are many factors even
21 influencing the course of a gas explosion, and we have
22 to simulate all this. It is the gas concentration,
23 which is important, also the gas clouds, how big is it?
24 If we talk about a center wing tank, is it everywhere?
25 Is it one or two of the base?

1 There could in fact be ahead of ignition
2 before we ignite, there could be turbulence in the tank
3 or in the geometry. The position of ignition source
4 has to be modeled, as well as what sort of an ignition
5 source do you have. You can in fact generally
6 speaking, you can have the flame jet ignite in the
7 clouds .

8 The geometry aspects, everything has to be
9 there, the confinement, possibly the vent openings, if
10 you want to do this deliberately, where are they? Are
11 they covered initially? Any equipment which is inside
12 your geometry, what you're looking at, and where they
13 are.

14 SO, all these aspects can differ from
15 situation to situation, and that means that the effects
16 of a gas explosion are scenario-dependent, so they are
17 strongly dependent on all sorts of factors which could
18 differ from accident situation to accident situation.
19 This has to be modeled.

20 That answers your question, Mr. Crider.

21 MR. CRIDER: Thank you, Kees.

22 Now that we have a general overview of the
23 processes, how do we apply those to the center wing
24 tank?

25 DR. THIBAUT: My next slide then.

1 (Slide)

2 DR. THIBAUT: You will see what we need to
3 be able to move this. First of all, we need to be able
4 to model the combustion, and the effect of turbulence
5 on the combustion. It has to be done everywhere. That
6 means both in space and in time.

7 We should also be able to model quenching, so
8 the turbulence that strong, that if you mix the
9 unburned gas and the burned gas very, very fast, that
10 the flame in fact quenches, just like you. If you have
11 a match and you blow it out, in a way, similar. You
12 also have to be able to determine the effect of
13 temperature and pressure which is changing during an
14 explosion on the combustion.

15 The fuel dynamics. I don't have to introduce
16 the term any more, but we have to describe the flow in
17 space and in time. We have to describe in terms of
18 generation and the dissipation. We have to describe
19 geometry aspects, in particular in this case, the
20 passageways stringers, the vent stringers, possible
21 ullage partitions. All of that has to be modeled.

22 My next slide.

23 (Slide)

24 DR. THIBAUT: You see what also has to be
25 modeled, but it could be distribution. It doesn't

1 necessarily have to be the same everywhere. If that is
2 the case, we should also be able to mix the gas ahead
3 of the flames, so what is happening is that if you have
4 a cloud which is varying in concentration through the
5 center wing tank, you should be able to describe the
6 mixing of unburned gas from one bay, which may have a
7 different composition into another bay, and then they
8 mix. That may happen ahead of the flame, and that has
9 to be modeled, as well.

10 Obviously, we have to be able to simulate or
11 describe the effect of ignition location, and some more
12 difficult aspects, like lofting of liquid fuel,
13 interaction of the flame with that fuel, as we saw in
14 the last experiment which was shown by Dr. Shepherd.

15 And also, something like the interaction of
16 the fluid dynamics which failing partition. So, once
17 the partition is failing, you will get a different flow
18 around that partition that you would have had if it
19 would have been, for instance, at one place all the
20 time, for instance, with the hinge open.

21 But if it really starts moving, the fluid
22 dynamics has to flow around that flying object, has to
23 be described as well, because it could be important for
24 the explosion. So, those are the processes we should
25 be able to model for this particular problem.

1 MR. CRIDER: Thank you, Kees.

2 I would now like to turn the questioning over
3 to Dr. Bower, who has some questions for Dr. Baer.

4 DR. BOWER: Thank you, Dennis.

5 Dr. Baer, it was pointed out in Dr. Birky's
6 opening presentation, we're following basically two
7 lines of computational modeling, funding two efforts,
8 and as pointed out in your opening bio, you have been
9 at Sandia National Labs for quite some time doing
10 computer modeling.

11 I was wondering if you could tell us about
12 some examples of computer modeling you've done at
13 Sandia Labs.

14 DR. BAER: Okay. I have two examples that I
15 can share with you. Basically, if both examples have
16 to deal with forming teams attacking a problem
17 association with accidents, and how we've implemented
18 modeling to look at these accidents.

19 The first example comes from studying studies
20 in safety, and can I have the first overhead?

21 This was some work that was sponsored by the
22 Nuclear Regulatory Commission. It was a study of a
23 hypothetical loss type accident in which hydrogen gas
24 is produced, and there is a possibility of a combustion
25 event that would result.

1 Sandia's program including emerging analysts
2 and experimentalists and combustion experts from
3 universities, as well as those from our own Combustion
4 Research facility in Livermore. The study was truly
5 aimed at trying to assess the containment integrities
6 and assess any sort of damage that might occur in a
7 containment vessel.

8 As we saw in Kees' presentation, flow
9 blockages and internal obstacle can have a tremendous
10 effect on flame accelerations, and this was also a part
11 of that study. We use modeling to evaluate not only
12 the over pressures, but also investigation how we can
13 use various schemes to reduce the over pressures, to
14 mitigate the combustion of that.

15 By and large, all these studies truly did
16 merge, experiments with modeling, and the outgrowth of
17 this is that we became very familiar with things like
18 scaling roles, and truly developed a more engineering-
19 based type analysis.

20 In the second example that I want to share,
21 this is a little slightly different explosive type
22 study. This is a study that I also participated in,
23 and this was the reinvestigation of the USS Iowa
24 incident. This was done with the U. S. Navy, and we
25 were aimed at trying to determine a probable cause for

1 the explosion that took place in the 16-inch gun aboard
2 the USS Iowa.

3 As you may well recall, this incident
4 resulted in the tragic life of 47 sailors. What's
5 different to the nuclear reactor events, is that this
6 combustion really deals with gun propellant; however,
7 when a gun propellant burns, it generates a lot of gas,
8 gas generation, and it also induces rapid
9 pressurization.

10 In fact, an important clue from the event
11 evolved because the projectile that was locked in the
12 gun traveled only part way up the barrel of the gun,
13 and this left a very important clue to determine where
14 ignition first began. We used modeling to assess a
15 probable location of ignition by also doing some
16 comparisons to full scale gun tests.

17 From that information, then we could
18 determine a pressure time history, which would then
19 tell us the loading onto the projectile, and from the
20 loading, we could determine that ignition first began
21 near the projectile and the propellant train.

22 Where this took us then was, modeling
23 actually told us then to focus our studies, focus in on
24 how the propellant train interacted with the projectile
25 during loading, and as it turns out, this was the key

1 in discovering that a high speed over ram could trigger
2 the combustion event.

3 SO, in both these cases modeling can be used
4 in a very effective way as a diagnostic tool and
5 accident type analysis.

6 DR. BOWER: By viewing that graph, those
7 graphs on that chart, we see you have had some good
8 results from using your type of computational modeling.
9 Do you think you could briefly discuss your
10 computational approach?

11 DR. BAER: Okay.

12 DR. BOWER: As briefly as possible.

13 DR. BAER: Yes. Before I describe it,
14 though, I think it's important to point out that once
15 again, the combustion process is an immensely difficult
16 problem to describe and model. You can't forget that.

17 CHAIRMAN HALL: That equation, I understand.

18 DR. BAER: At Sandia, we also have one of the
19 largest and most powerful machines available to us in
20 the world, and I've used the machine, and I can tell
21 you that this modeling problem in its entirety, if you
22 describe it in its entirety, it's beyond its
23 capabilities.

24 CHAIRMAN HALL: Dr. Baer, would you permit me
25 to just interrupt you at this point.

1 DR. BAER: Absolutely.

2 CHAIRMAN HALL: And make a comment, and I
3 want to direct this specifically to the families, and
4 of course, also, to the American people.

5 If it is humanly possible to find out what
6 the ignition source was that caused the center fuel
7 tank on TWA 800 to explode, and how it can be fixed, we
8 are committed to doing that, and we've tried to put
9 together the very best experts in the world that we
10 know, and that's what this panel is all about.

11 I get many questions from the media, as our
12 other Board members do and our staff does, "What is
13 taking so long?" And I hope again, this panel
14 demonstrates in a very thorough way in which this whole
15 situation is being approached and in which we are
16 trying to get to that conclusion.

17 I do not know, as you don't know whether we
18 will ever have an answer as to what the ignition source
19 was, but I want all of you all to know that in the
20 summer of '96, once we knew what had happened, I asked
21 Dr. Loeb and Dr. Ellingstad to start assembling, if we
22 could, the best experts in the world to try and solve
23 that problem because I know how much it means to the
24 families. I know how much it means to the American
25 people.

1 I went out to Sandia and heard a
2 presentation, and Dr. Baer showed me what they had done
3 with the USS Iowa investigation, and which is in some
4 ways similar, and which I think you were trying to find
5 the ignition source there for that explosion; and I
6 don't know where we are in all this, and there are not
7 going to be any conclusions because Dr. Shepherd and
8 all the others that you will hear from today are in the
9 middle of things that probably won't be completed until
10 next year.

11 But I wanted to be sure that we go through
12 this in as much detail as possible, and that's what
13 we've been doing.

14 So, please proceed. So

15 DR. BAER: So, in developing our modeling
16 strategy consistent with the time constraints so that
17 with the impact the quarter scale testing. This really
18 strongly suggested to us that our modeling direction
19 should take the more engineering-based type approach,
20 following a lot of our prior experience and studies
21 that we've done in the past.

22 To that end, what we chose to do was to seek
23 some approximations that would allow us to solve to
24 model the combustion event, and the first approximation
25 we chose to invoke was, we chose a limit where the

1 motion of the flame is much slower than the speed of
2 sound, and this, as it turns out, greatly simplifies
3 the model description.

4 Furthermore, we chose an approach where we
5 don't really solve all the details of the flame
6 structure. That in itself is an incredibly complex
7 problem. Overall, what we're aimed at was describing
8 the transient pressures in the various compartments
9 within the tank, because after all, it's the pressure
10 differences that define the forces on the internal
11 structure, and that's really what we aimed at trying to
12 get at.

13 so, as Paul mentioned here, in formulating a
14 model, we always start with some very basic physical
15 laws, and those laws basically say we're going to
16 conserve maximum/minimum energy, and when we impose the
17 simplifications, the approximations, for example, on
18 momentum, it says that the pressure inside an
19 individual compartment is spatially uniform.

20 so, we start with these sort of simplified
21 equations of motion.

22 Then what we do is, in each region where the
23 flame has penetrated, we solve these equations
24 separately for both the burned and unburned portions of
25 the bay. We also allowed gas motion to take place

1 between the compartments. That's real important
2 because that really kind of establishes the turbulence
3 levels.

4 And this is taken care of by invoking
5 engineering approximations for gas flow by pressure
6 drop correlation. From our prior work, we know that
7 adding heat, including heat losses, is a very important
8 thing to do, particularly in large-scale type
9 commercial events.

10 so, thermoradiation and heat convection were
11 also included in our analysis.

12 The combustion has been simplified by
13 treating it as a moving interface, and what that really
14 means is that across this interface, there is a jump in
15 state. It suddenly changes in temperature and density
16 and composition, and that there are some well-known
17 additional conservation laws associated with jump type
18 conditions that we also preserve.

19 The flame algorithm is really a very dynamic
20 one. It basically relies on a mesh that follows the
21 individual flame list. Flame accelerations is also
22 included and it is included by evaluating the
23 turbulence characteristics of the gas motion, and using
24 the empirical type, flame acceleration type burn loss.

25 That, in essence, is our model.

1 DR. BOWER: I notice you mentioned that you
2 did include some approximations; how does that effect
3 your computational time or your time and ability to
4 repeat a computation, et cetera?

5 DR. BAER: Oh, that's a very important issue
6 because by invoking these simplifications, now we have
7 a model that we can run hundreds and hundreds of times.
8 In fact, we have done that, so it's something that is
9 very quick, very easy, and it's very much adaptable to
10 addressing experimental type comparisons.

11 DR. BOWER: Do you have any results of the
12 type of modeling you've done related to this
13 investigation in the quarter scale testing that's been
14 done so far that you could share with us?

15 DR. BAER: Okay. Again, we're only halfway
16 through this study, but the first thing we did was, we
17 chose to model some laboratory type scale experiments
18 because we needed parameters like burn velocities to
19 include in our modeling.

20 May I have the first overhead.

21 SO, this is a comparison of our modeling to
22 the laboratory scale experiments that were done at CAL
23 Tech. This is one example, and I'm showing the
24 pressure time histories, comparing the experimental
25 data with the model.

1 The reason why we choose laboratory scale
2 experiment to first model is that it's a very simple
3 geometry to deal with, and what we're really after is
4 some very basic important parameters to the modeling.

5 Having this information at hand, we then can
6 turn to a geometry that's more representative of the
7 quarter scale test, and now we're looking at
8 essentially, this was test number 11, a quarter scale
9 test, in which there were no partitions.

10 so, it's just one single compartment, and
11 again, we're using the Jet A simulant hydrogen propane
12 mix, and I compare the over pressure versus time model
13 calculations to the quarter scale test, and the results
14 look quite interesting and intriguing, and encourage us
15 to then go to the next step.

16 That next step is now to look at adding the
17 effects of the internal structure, the partitions,
18 individual bays. So, what I'm going to show is an
19 animation of what our calculation looks like, but this
20 is the geometry. This is test number 4, and we're
21 going to begin ignition in bay 5, although in the
22 animation, the individual bays are shown there, we do
23 not show the individual passages.

24 This graphic does show that there is indeed
25 connected flow passages between the bays, and it is

1 this effect that has a very important role in
2 accelerating the flames.

3 SO, can we see the animation?

4 This is the quarter scale test simulation, .2
5 seconds in duration, and what we're going to see again
6 is first, the very slow-moving expanding bubble that
7 will begin to fill bay 5, and then once it interacts
8 with the walls, the combustion greatly accelerates as
9 it moves from bay-to-bay.

10 so, we will repeat this now with just the
11 accelerated part. We will slow down the motion of the
12 turbulent burn part, and really, what this illustrates,
13 as simplified as this modeling is, it's still very
14 complex, and that this is really a cat-and-mouse game
15 where the combustion is moving between compartments and
16 moving through the orifices, and accelerating and
17 sweeping through the whole domain.

18 So then, we can now turn and look at what
19 calculations versus experiments look like, and here, I
20 show the overlay of the calculations to the
21 experimental data for both the case where combustion
22 began in bay 5, and it traversed through the last bay.

23 The results look quite interesting. Again,
24 we're only halfway through our investigation. We've
25 got a lot of work yet to do, but this kind of

1 illustrates what our modeling can do.

2 DR. BOWER: Thank you, Dr. Baer.

3 At this point, I'll turn the questioning back
4 over to Mr. Crider.

5 MR. CRIDER: Thank you, Dr. Bower.

6 I'd like to continue with some questions for
7 Kees . Could you briefly describe what is your model at
8 CMR ?

9 DR. VAN WIN GERDEN: Could I have my first
10 slides, please.

11 (Slide)

12 DR. VAN WIN GERDEN: So, we are using a code
13 called FLACS. It's Flame Acceleration Simulate. It is
14 a C of D2, and that is at the moment used quite heavily
15 by industry, gas and oil industry, especially for gas
16 explosion analysis. It has a 17-year of development
17 history behind it, and we have used about 160 men years
18 to develop it. That includes supporting experiments
19 and things like that.

20 In 1997 this code was used to do consequence
21 studies for several oil and gas-producing facilities in
22 the North Sea, and that's why it has been developed
23 especially for that purpose.

24 Next slide.

25 (Slide)

1 DR. VAN WIN GERDEN: You will see a typical
2 application, so this is an off shore rig and module of
3 an off shore rig. It contains some openings. The roof
4 has been taken off so that you can take a look into it,
5 and a lot of things like that. That's why you have
6 this interaction of the flame, the combustion, with
7 turbulence generated at these obstacles.

8 so, it's a very complicated process which is
9 tried to be simulated here.

10 so, FLACS has also been used at some incident
11 investigations . We mention three here: West Vanguard.
12 We used a drilling rig which has an explosion in 1985.
13 Piper Alpha, which is a very dramatic explosion where
14 167 people were killed; and BEEK, which was a land base
15 geometry, and naphta cracker where a vapor cloud
16 explosion occurred.

17 Just to show what FLACS, how we were involved
18 in the public inquiry of the Piper Alpha investigation,
19 it has some similarities with the present situation.
20 We wanted to know where ignition occurs, and so if I
21 can look at the next slide to see the Piper Alpha
22 accident.

23 (Slide)

24 DR. VAN WIN GERDEN: Piper Alpha is a
25 platform, and there was a small minor explosion which

1 occurred in the compressor module. If you look at the
2 next slide, you will see that the compressor module is
3 Module C, and the Module D is the control room.

4 Explosion in Module C caused the wall between
5 C and D to fail, and as a result of that, they lost
6 power, and because of some peculiar circumstances, they
7 had no power either on the fire pumps, and as a result
8 of that, they got a very major fire after this initial
9 explosion, and they lost complete control, and
10 everybody is given the instruction to go to the living
11 quarters on the module in case of a major event, and
12 especially that living quarters ended up in a very big
13 fire ball, and lost of smoke, and many people lost
14 their lives because of that.

15 The incident started in Module C, and there
16 was a gas detection system which detected some gas in
17 Module C, and the question was posed to us, whether an
18 explosion of death cloud? If you construct a cloud
19 which occurred in the corner in Module C, the green
20 area, where that could give rise to pressures which
21 could cause this incident, and that was what we found,
22 and we found that the pressure was about .3 bar, could
23 be generated by this explosion, and that will be more
24 than sufficient to have the go between Module C and D
25 to fail.

1 so, that is why we were involved in the Piper
2 Alpha accident investigation.

3 MR. CRIDER: What is your basic computational
4 approach with FLACS?

5 DR. VAN WIN GERDEN: Well, FLACS is a C of D
6 code, and my next slide, it just shows some features.
7 It calculates the compressible turbulent directed flow.
8 It has some miracle solvers. There are flame models in
9 it. It calculates the thermodynamics, all that to
10 describe this complex process of an explosion,
11 interaction with the geometry in which the explosion
12 occurs.

13 SO, what we do is, we put a grid around or on
14 the geometry, and we calculate all parameters which are
15 shown on the next slide.

16 (Slide)

17 DR. VAN WIN GERDEN: The parameters which are
18 pressure velocity, so that's the energy which is
19 released. The turbulence throughout the entire
20 computational domain, the fuel fractions are the fuel
21 fractions of how much, how fast, or what is being
22 burned. Also, the mixed fraction which is the mixing
23 of the fuel ahead of the flame because of the expanding
24 combustion flow.

25 SO, then, we show a number of equations,

1 which I just want to show for the sake of, you could
2 almost say, fun. It is just to show you the complexity
3 of the problem, and this is just an approximation of
4 the problem, and we saw these equations in every
5 control volume throughout the entire computation which
6 typically has a numbers of nodes, 100,000, or 150,000
7 in which we solve all these equations.

8 In my next slide you can see an example of
9 how we treat the cells, are very fine in the geometry
10 where the explosion occurs until we use some coarser
11 cells around it, also, to be able to describe the
12 explosion around the module.

13 MR. CRIDER: How did you validate FLACS?

14 DR. VAN WIN GERDEN: So we validate those
15 certain models, and then as Paul Thibault already
16 introduced a way of validation, you first start
17 validating your submodels, which you have in the code.
18 That is something we do all the time. We almost yearly
19 issue a new code which is going through a validation
20 process which is very extensive.

21 So, we validate all the submodels in the
22 codes, and then we try to validate the whole thing
23 against experiments which have been performed in
24 complex geometries. So, I can just show you an example
25 of a geometry, so if we go over this because of time

1 problems, we can just go to the next slide.

2 Can we go to the next slide?

3 (Slide)

4 DR. VAN WIN GERDEN: Just an example of data
5 that has been used to compare the code. This is a
6 graph showing for many, many experimental rigs, varying
7 from small scale to very large scale, experiments were
8 done, and paid for by the gas and oil industry on a
9 scale of 3,600 cubic meters where they did experiments
10 in the module which could withstand about four bars,
11 which is about 60 psi.

12 so, you see a very good agreement between the
13 module, the model predictions and the experiments. And
14 I just want to emphasize the fact that not always,
15 experiments tell the truth either, because it is very
16 difficult to perform experiments, as well, and you can
17 have some variations there, as well.

18 so, I will say that this agreement is quite
19 good.

20 MR. CRIDER: Do you have some results for us
21 from the center wing tank work?

22 DR. VAN WIN GERDEN: Yeah, we do. So, two
23 slides further down or something like that. Yes, that
24 is your slide, your left hand, yes.

25 (Slide)

1 DR. VAN WIN GERDEN: So, this is an example
2 of pressure time is which were predicted by the code in
3 an experiment where, if you bear with me, I don't have
4 an example of the fuel tank, the slide of the fuel
5 tank. But the front spar is not there. The central -
6 what is it called? - the spanwise beam 3 if failing,
7 and all the others are not failing. An ignition is
8 occurring in Bay 5, which, according to Dr. Bower, is
9 bay left aft.

10 The ignition occurred in that bay, and then
11 you see the pressure time is reaching each bay and you
12 see some high pressures. Those are in the bays where
13 the partitions did not fail, whereas, the ones which
14 are much lower, are in fact in the bay 1, and in the
15 bay zero. The wall, the partition between bay 1 and
16 bay zero failed, and there was no wall, on the other
17 hand, of bay zero. So, the front spar was not there.

18 This is the kind of predicted pressure time
19 that you get.

20 MR. CRIDER: Okay.

21 DR. VAN WIN GERDEN: And I also videoed that
22 which shows some assimilation, and the idea is, first
23 of all, to compare with experiments.

24 If you could just start the video.

25 Could you hold it here? Thank you.

1 SO, this is the way you can see the
2 combustion propagating in the center wing tank. The
3 left one will show the development of the flame,
4 whereas, the right one will show the development of the
5 pressure, and that the development of the pressure is
6 showing changing of color.

7 If you have blue, it is low pressure. If you
8 go to the red one, you get high pressure. Now, I just
9 want to say that this first one is a simulation where
10 the walls are in fact failing. You won't see the wall
11 flying away because we cannot describe that, but we can
12 describe the failing of the wall by some analytical
13 method where the walls just stay in place, but they
14 open with varying velocity at that location.

15 so, on the left side, you will see the flame
16 developing, and on the right side, you will see the
17 pressure developing. First, it was done rather quick,
18 so remember, the walls are failing in this particular
19 one. Ignition occurs in bay 5, and you see how the
20 flame develops.

21 You may also see some jets in this particular
22 one bay, a 6. You see the pressure there reflecting on
23 the walls, giving some red colors, and also propagating
24 back into the tank. Just show it show once more. So,
25 if you pay attention to the right one, you can see that

1 there is some pressure waves in, I think, it's bay 2,
2 which occurred on the top side, and then reflected on
3 the bottom side. You get some red colors there which
4 indicate strong reflections.

5 This is a typical result. We assimilated
6 several other situations, as well. The next one is in
7 fact the one which was also shown by Dr. Baer. We
8 have two more which showed weak partitions where we
9 used mixtures, which are not the same as using the
10 experiments, but they are leaner, trying to
11 reconstructed the scenario which could have led to the
12 same damage as observed in the accident. So, that's
13 what we are trying all the time.

14 Now, at this moment, we use most of the
15 effort into trying to explain with the model what
16 happened in reality, so that we vary the concentration,
17 that we vary the ignition location.

18 Thanks .

19 MR. CRIDER: Okay, Kees. There is one more
20 question, I think, for you, in this series. Again,
21 we've had good communication between the team members
22 on this, and how does it compare, your work, compare
23 with the experimental work, and again, comparing with
24 Mel's results?

25 DR. VAN WIN GERDEN: We made the comparison

1 forthwith. It is test number 4. If we can have the
2 overhead.

3 You see here the pressure time is 3 in one of
4 the bays. I'm not sure which one it is. It's shown on
5 the overhead at the moment on the left side. It's in
6 bay 1. That is the bay between spanwise beam 3 and
7 spanwise beam 2.

8 There, you see the three different curves.
9 You see the experiment, which is the one which has the
10 vibrations on the top. You see the FLACS one, which is
11 blue, and the Sandia one, which is red. And you see
12 that there is also not only in rise time, but also in
13 fact, a moment of arrival of the peak pressure, very
14 good agreement between both the codes and the
15 experiment.

16 And you see that this is in fact the case for
17 other bays, we well. We could, of course, show them
18 all, but just another example showing how the
19 comparison is. It's promising.

20 DR. BOWER: All right. There is one more
21 item we have. Do you have a comparison of the
22 approaches, that is, a tabular, something to compare
23 the approaches?

24 DR. VAN WIN GERDEN: Yes. We have a table
25 comparing the two codes where you can see what the

1 differences between the codes are, and I think I should
2 emphasize then on the differences, because there are
3 also some similarities.

4 But I think the differences are in the flue
5 dynamics. There were some differences in the heat
6 loss. The heat loss may be very important, especially
7 for slower events. During the combustion phase, the
8 flame will lose energy to the environment. That is
9 modeled, as well, in both codes.

10 But then in the Sandia code it is mainly
11 radiation, drizzles of convection, as in the FLACS
12 code, it is mainly convection. In fact, we also see
13 that the Sandia code at the moment at least, could not
14 handle failing partitions which FLACS up to a certain
15 extent and handle.

16 Both codes could not handle interaction with
17 liquid, so lofting of liquid cannot be handled.
18 Neither can we handle the interaction of a panel which
19 is flying through the center wing tank after it fails,
20 and the interaction of that panel with the flow.

21 There is also a difference in the gridding.
22 In FLACS we have a cetacean grid which means it's a
23 square kind of grid, just blocks everywhere, cells; but
24 we do not have local grids refinement as the Sandia
25 code has.

1 MR. CRIDER: All right. Thank you, Kees.

2 I'd like to turn the questioning over to Dr.
3 Bower, who has a couple of final questions for this
4 modeling subsection.

5 DR. BOWER: I guess I'll direct this right to
6 Dr. Thibault. Keeping in mind that our original
7 objective in all this modeling and testing program is
8 to help find an ignition location. We have seen some
9 examples of how modeling is done to match the quarter
10 scale experiment so far.

11 Could you just give a brief comment on what
12 type of calculations you see on-going in the future to
13 help us perform our original objective in defining the
14 ignition location?

15 DR. THIBAUT: What we have is an analysis of
16 an accident. We are trying to figure out where the
17 ignition occurred. There are few things that we don't
18 know, and there are few things that we have some
19 information on. What we don know is the ignition
20 location. That's our job to find out.

21 We don't know exactly the concentration and
22 concentration distribution in the tank, but thanks to
23 those very important flight test data, we have some
24 information on the range of concentration, and
25 concentration distributions we might expect, and that's

1 very important. So, we have that information. We have
2 some information - and this is a difficult part - we
3 have some information on the damages to the tank.

4 As mentioned, some of the partitions failed,
5 and some didn't. So, what we have for us is that we
6 have a limited knowledge of the damages. Basically,
7 just what I said, some partitions fail and some dent,
8 and we know which ones those are.

9 We have some idea of the fuel concentration
10 distribution, and that's flight test data. So, what we
11 need to do is to vary the ignition location, vary the
12 fuel concentration distribution, and figure out those
13 scenarios - the scenario - or those scenarios that are
14 consistent with the damages that we observed. That
15 basically involves a parametric analysis to figure out
16 which scenarios are consistent with those damages.

17 DR. BOWER: Do you anticipate that any
18 studies will lead to a unique scenario that could have
19 caused these damages, one particular unique solution?

20 DR. THIBAUT: Well, we have two things that
21 we have to understand here. First of all, as Dr. Baer
22 said, this is a very complicated process, and we have
23 to do the best job we can with our models, with
24 validation and with experiments. Where we are right
25 now, we are in the validation phase, so that's where we

1 are in the process. So, we haven't really started
2 answering that question.

3 But the other thing that we have to
4 understand is that even assuming that our models were
5 to be perfect, absolutely perfect, what we have is that
6 we have some panels failed, and some panels didn't
7 fail; that's the information we have. And we have to
8 figure out those scenarios that are consistent with
9 that.

10 It could be that we find no scenarios. It
11 could be that we find a narrow regime of scenarios,
12 which would be very helpful in locating the ignition,
13 or we may find out that there are quite a few of
14 scenarios that could lead to that result, even with the
15 most perfect models.

16 so, where we are in our investigation, that's
17 all I can really tell you about what we're likely to
18 find out.

19 DR. BOWER: Thank you for that very candid
20 answer, Dr. Thibault.

21 I am going to turn things back over to Dr.
22 Birky.

23 DR. BIRKY: Yes. In the light of the hour, I
24 had a lot of questions to ask Dr. Shepherd, but we
25 won't do those now, but what I would like to do is,

1 summarize what we know today, the good news and perhaps
2 the bad news, and we've heard that we haven't located
3 the ignition source.

4 But I think we do know the following:

5 (1), we know that the flammability, the
6 temperature in that tank was above the flammability
7 limit in flight; (2) we know how to reduce that
8 temperature significantly; (3) we know that the
9 ignition energy goes up rather significantly as the
10 temperature of that fuel goes down; (4) we know that
11 our best methods to reduce that temperature beyond the
12 addition of fuel.

13 I think we heard a suggestion today from
14 Boeing about radiation shield and a little bit of
15 ventilation.

16 All of those things would contribute to
17 reduction or increase of the temperature.

18 CHAIRMAN HALL: Yes. Let's get a comment and
19 then we will move to break here, because I'd like to
20 finish this panel today, if we can, and we haven't had
21 the opportunity for the party questions, or the Board
22 of Inquiry, so it looks like we're going to be here for
23 a while, so we will get a comment from Dr. Shepherd and
24 then take a nice break and come back and finish our
25 work.

1 DR. SHEPHERD: The only comment I'd like to
2 make at this time is that I believe that I'd like to
3 second your earlier comments, Mr. Chairman, and that
4 this group has worked over the last six months together
5 to try to integrate our findings in the laboratory and
6 our field testing, quarter scale experiment and the
7 modeling towards this goal of identifying the ignition
8 source.

9 We are going to continue to work at that, and
10 I hope to be able to report back to you in a much more
11 positive way.

12 Thanks .

13 CHAIRMAN HALL: Anything else, Dr. Birky?

14 DR. BIRKY: No, sir. We can take a break.

15 CHAIRMAN HALL: Well, let me say, Dr.
16 Shepherd, first, how much -- and we got the party
17 question, and this is certainly no summary because
18 we've got plenty; but I do want you all to know how
19 much I appreciate all of you gentlemen and the various
20 organizations that we have reached out and tried to
21 assemble all the work that you have done.

22 I certainly understand again that there is no
23 guarantee that we're going to have an answer, but I do
24 want to stress again, I want to be sure that the
25 American people and those who lost loved ones on the

1 flight, know that we're doing everything we can.

2 I appreciate very much what I heard today
3 from FAA and Boeing, that they are moving ahead now to
4 not only look to eliminating the ignition sources, but
5 looking also at ways to reduce the vapors; and I think
6 that's a very positive report, and I appreciate that
7 very, very much.

8 so, let's take a break until 6:30.

9 DR. BIRKY: Mr. Chairman?

10 CHAIRMAN HALL: Yes.

11 DR. BIRKY: May I just interrupt one moment,
12 please? Can I say to this panel, the contractors we
13 have on this program, in my 35-year professional
14 career, I don't think I have ever worked with a better
15 group, and it's a very impressive group, and I
16 appreciate their activities and their work
17 tremendously.

18 CHAIRMAN HALL: Well, I asked you all to put
19 the best together. If this isn't the best, we will
20 find out if there are any more we need to add; but I
21 appreciate that, Merritt. That was a nice comment.

22 All right. Unless the parties have
23 objection, I'd like to get this panel finished today;
24 otherwise, we may be doing this Friday night, and I
25 assume everybody would rather do it tonight.

1 I'm hearing, seeing nods of agreement at all
2 the tables except Honeywell.

3 Honeywell is now nodding.

4 But let's take a nice break until 6:30, and
5 then we will come back and continue the session at that
6 time.

7 (Whereupon, a brief recess was taken.)

8 CHAIRMAN HALL: We will reconvene this
9 hearing of the National Transportation Safety Board.

10 We have just heard from our expert panel in
11 the area of flammability, and before we move to the
12 Party table, Dr. Birky tells me he has a couple of
13 brief questions he is going to address.

14 DR. BIRKY: Really, I think just one.

15 I wanted Dr. Shepherd to show his information
16 on ignition function as a function of temperature.
17 That study, I think, is very informative in terms of
18 reducing the risk of ignition in the center wing tank.

19 Dr. Shepherd, could you do that?

20

21 Presentation By

22 DR. JOSEPH SHEPHERD

23

24 DR. SHEPHERD: Yes. I believe that this is
25 one of the most important results of our laboratory

1 testing, we had some notion about flammability limits
2 and BEEK pressures from the previous work that had been
3 done, although there was a great deal of uncertainty
4 about the application to this particular accident; but
5 about this particular area, ignition energy, we had
6 almost no information, and what is most striking to me
7 is that when you look at this picture, you see - and
8 it's important to note for everyone who is not familiar
9 with working for logarithmic curves - that the axis on
10 ignition energy expressed a range of 100,000 between 55
11 or 60 degrees Celsius, that is, 140 Fahrenheit, which
12 is the type of temperature that was measured in the fly
13 test, and a temperature which would correspond to a
14 moderate day, or even a warm day, 86-to-90 degrees
15 Fahrenheit.

16 This enormous range in ignition energies, I
17 believe, indicates that there is a significant gain
18 that could be made in safety if the temperature of the
19 fuel can be reduced.

20 DR. BIRKY: Thank you, Dr. Shepherd. That's
21 all the questions I have.

22 CHAIRMAN HALL: Very well. Thank you, Dr.
23 Birky, and thank you, Panel.

24 We will now move to the Commercial Airplane
25 Group - Mr. Rodrigues.

1 MR. RODRIGUES: Boeing has no questions, Mr.
2 Chairman. Thank you.

3 CHAIRMAN HALL: The Airlines Pilots
4 Association Captain?

5 CAPT. REKART: Yes, sir.

6 I guess, Dr. Shepherd, there has been some
7 discussion about the fuel weathering and its affect on
8 flammability. Have there been any efforts to
9 characterize the weathering as a function of pressure
10 and temperature, or is it strictly a function of time?

11 DR. SHEPHERD: Let me answer that by
12 discussion in a little bit more detail the weathering
13 issue. I had hoped that we would have had time for Dr.
14 Sagebiel to spend a little more time on that because he
15 looked at that in some detail.

16 The data were expressed in terms of time when
17 he discussed, but the primary consideration we need to
18 make is this: What is weathering? Weathering happens
19 because when the fuel gets hot, it vaporizes, and then
20 when you climb after you take off, you vent that air
21 and the fuel in it out of the tank as the pressures
22 goes down.

23 SO, what you're doing is, you have a little
24 pump there. You vaporize some of that fuel, and then
25 you suck that fuel out of the tank. Now, if you leave

1 the same fuel in the tank, and you do that repeatedly,
2 as they did in the flight test, every time you heat up
3 that fuel tank and climb up in that airplane, you're
4 pumping out that vapor, and when you're doing that,
5 you're withdrawing, as Jim Woodrow showed, the lighter
6 components.

7 SO, the key parameters are really not time,
8 but the number of times that you pump on that liquid,
9 that is, how many times do you climb and descend?

10 Now, in the case of the fuel from Athens and
11 back, that was exactly once; right? And not only was
12 it once, but at the point when the airplane was
13 climbing, in fact, there was a good deal more fuel in
14 there than the 50 gallons that was tested in the
15 Evergreen flight test, and we don't know what the
16 temperature was of that fuel at the time it left
17 Athens . I don't have any details on that. Maybe there
18 are some. Dr. Birky is shaking his head, "No."

19 SO, I think in fact, the weathering issue is
20 now very significant for this accident.

21 CHAIRMAN HALL: Does Dr. Sagebiel want to add
22 anything to that? Dr. Shepherd says we cut you short.
23 We don't want to cut anybody short.

24 DR. SAGEBIEL: Yes, sir. I could just re-
25 emphasize what Dr. Shepherd just showed, and I don't

1 know if we're going to risk doing this, but we might
2 actually switch the video plus here, and try and get --
3 if we can speak to this momentarily.

4 There is a figure I would like to show you -
5 there it is - that describes the flight sequence.
6 Okay, it's still on there; that describes exactly what
7 Dr. Shepherd stated, and that is, that the fuel was
8 added down here at times zero on this figure, and the
9 aircraft, the test aircraft, that is, in the flight
10 test program, went through these excursions to 19,000
11 feet.

12 Okay. My apologies. I must have hit
13 something there; went to an excursion to 19,000 feet,
14 went to another excursion all the way to 35,000 feet,
15 another excursion to approximately 17,500 feet, another
16 excursion to 35,000 feet; and then a vapor sample was
17 taken here during climb at nearly 60 hours of flight
18 operations, and that vapor sample, we were still able
19 to reach a fuel air mass ratio that was in the
20 flammable range.

21 This is many more excursions up and down,
22 which is what weathers the fuel. The amount of time
23 spent at any one particular altitude, say, up here, is
24 not nearly as relevant to the weathering as is the fact
25 of the going up and down. The fact of going up and

1 down has a much greater impact on the weathering than
2 does the actual time spent at any particular altitude.

3 And I have some additional data that
4 describes the tank venting.

5 Dr. Birky, would you like me to describe the
6 venting tank data?

7 CHAIRMAN HALL: Yes. Proceed. Now, the
8 taxpayers paid for a lot of all this, so we want to
9 hear it all.

10 DR. SAGEBIEL: Very well. In the analysis of
11 the samples that I conducted, I did actual several
12 analyses, and to get as much information as these
13 samples, as I said, these were the first, and as far as
14 I'm aware, the only time we have ever actually sampled
15 the tank --

16 CHAIRMAN HALL: You don't have a picture of
17 that, do YOU?

18 DR. SAGEBIEL: Yes, I do.

19 CHAIRMAN HALL: Dr. Bower took me over the
20 plane where the bottles were. I think that would be
21 interesting to show if you had a picture of how you did
22 that.

23 DR. SAGEBIEL: Sure, I will be happy to. In
24 fact, I will do that right now.

25 CHAIRMAN HALL: When you talk about taking

1 vapor samples out, it's hard for someone to maybe
2 visualize that.

3 DR. SAGEBIEL: The samples were collected in
4 the pre-evacuated one liter stainless steel cylinders,
5 what I refer to in my business as cans or canisters.
6 These are commonly used in air sampling to collect an
7 air sample. These are a very convenient device for a
8 number of reasons. It can be made very, very clean.
9 It can be checked for cleanliness, and then evacuated
10 so that when it's exposed to air by opening a valve, it
11 draws an air sample into the cylinder.

12 The cylinders are also quite durable, and
13 they can be shipped by any number of means, including
14 the U. S. Postal Service, Fedex, UPS, you name it, to
15 another location, and they maintain their integrity.
16 They maintain the integrity of the sample.

17 In this case, the canisters were connected to
18 the center wing tank by a manifold in a small one-
19 eighth inch stainless steel sampling line, and that
20 line of manifold were purged immediately prior to each
21 sample, so that we were sampling a representative
22 sample.

23 Just so you get an idea of positionally where
24 this was in the aircraft, this is a top view now with
25 forward being at the top of this figure, you're looking

1 down on the center wing tank with the stained
2 conventional beams being drawn in here.

3 The sample was collected in the space between
4 spanwise beam 3 and spanwise beam number 2
5 approximately 12 inches away from spanwise beam number
6 3, and approximately 35 inches up from the floor level
7 of the tank. The line traversed across the Drive A to
8 the light on the aircraft, and then into the forward
9 cargo bay.

10 Sampler then was attached there, and this is
11 what it looks like from the top down looking at it.
12 These are the one liter bottles. This box was designed
13 to be completely sealed. There would be a top lid on
14 it during operations, and that's just to prevent any
15 possibility of any leaks, allowing fuel vapors into
16 parts of the aircraft. They are obviously not
17 desirable.

18 The canisters have their own shut-off valves
19 here with the small mural knobs, and then were
20 connected to this manifold to a second shut-off valve
21 that was operated through the box so that the stems of
22 those valves go through the box so they could be
23 operated from the outside.

24 In the actual aircraft it was something like
25 this . It's not quite as good a picture. You can see

1 here, this is the forward spar where the arrow is
2 sitting, the thud spar where the arrow is sitting back
3 here. This is one of the water bottles that gets
4 discussed and was discussed as they were simulated in
5 the quarter scale tests.

6 And this is the actual manifold enclosure as
7 it was ready for flight with a strap down over the top
8 of it, and ready to go flying. So, that's the actual
9 locations of the physical operation.

10 If I can jump back then momentarily here.
11 One of the findings that we had in the samples was
12 something called an HCSC, and not to get too heavy with
13 acronyms, it's a hydrochlorofluorocarbon. You may only
14 be familiar with chlorofluorocarbons, CFC'S which used
15 to be used as the common refrigerants. CFC 12 is what
16 is in those common air-conditioning and refrigeration
17 type applications.

18 These had been replaced because they are
19 ozone depleting chemicals. That's a whole another
20 discussion, and they have been replaced with these
21 hydrochlorofluorocarbons which are chemicals that are
22 much less destructive distress.

23 In any case, a can of material containing the
24 hydrochlorofluorocarbon number 141B was used to test
25 the thermocouples. This was sprayed onto the

1 thermocouples, as this was described to me by Dr.
2 Bower, and used. That would then cool that
3 thermocouple, and that gave an indication on the data
4 system and allowed the data system operator to confirm
5 that the thermocouple was in fact connected and
6 operated.

7 so, this is thermocouple testing that took
8 place in the tank. As a result, there was a residue of
9 this chemical in the tank, a very small amount, mind
10 you, but in my analytical capabilities, this type of
11 chemical can be detected very, very easily. It is
12 among the most easy to detect chemicals that are
13 commonly found in air.

14 HCFC 141B is stable certainly under the
15 conditions in that tank, which is to say, no sunlight,
16 no further chemical activity. It is inert, for the
17 most part, not going to react like the fuel molecules,
18 and there is no source of it in the tank which
19 contrasts with the fuel, which of course, had a liquid
20 source in the tank during the flight test.

21 Unless the behavior of this chemical is going
22 to be subtlety, yet very importantly different from the
23 fuel, whereas, as the fuel weathered during the
24 excursions up and down in altitude, this compound is
25 not going to weather because it's a single compound,

1 and it is going to leave the tank, based on, as we
2 described, these excursions up and down in altitude.

3 Just to show you why I went after this, this
4 is a chromatogram of one channel, what we call the ECD,
5 or electron capture detection, part of my analytical
6 system, and when I saw this, I was expecting only to
7 see oxygen because oxygen responds on here, and when I
8 saw this other component out here, and you can see that
9 that's essentially a rise in this signal here,
10 indicates a component eluding from the system, this was
11 essentially the only other rise. This is some noise
12 caught generated by the fuel that's being analyzed at
13 the same time.

14 so, obviously, I found this to be very
15 interesting from a scientific standpoint, and it turned
16 out to be interesting from the standpoint of flight
17 tests. When we consider this in relative concentration
18 amounts, that is, the HCFC to air ratio, going up in
19 altitudes, since both the HCFC in the air or venting at
20 exactly the same rate, they are both pure gases under
21 this standpoint, there will not be a change in
22 concentration, and that is approximately what we
23 measured within an error of about 4.8 percent; that
24 those three samples were exactly the same for our
25 purposes.

1 On the second flight, similarly, those three
2 samples were the same, but much lower; and on the third
3 vapor sampling flight on the 16th, those concentrations
4 were again much lower, yet again, precision even better
5 than it was earlier in the flight test.

6 This indicates that we had a good sample
7 collection. This indicates that the sample collection
8 was not in error because had this ratio changed, the
9 HCFC to the air ratio changed, we would have indicated
10 a problem.

11 We tried to use this then to understand tank
12 venting, and in order to that, we made a calculation
13 based on the expected concentration from the first
14 flight test where there was a vapor sample, through the
15 rest of the program, based on the excursions to
16 altitude, making estimates based on the pressure that
17 the tank was exposed to at the maximum altitude of any
18 given flight and to the temperature of the air at that
19 point because as the plane begins to descend, it draws
20 in slightly cooler air than the actual tank.

21 As I said, this is very strongly tied to the
22 weathering of fuel. The results of those calculations
23 were very good where we were able to show here -- now
24 again, this is a quarter of magnitude scale because the
25 concentration dropped off quite rapidly, but there are

1 three triangles up here indicating the three observed
2 values from the first flight test; three triangles
3 again here, and the line showing how we calculated
4 where this point should be, and again, how we
5 calculated where this point should be.

6 And what I want to say here is, the ability
7 to calculate the concentration show the tank venting,
8 is in fact very well understood, based on these
9 excursions in pressure, and that is very critically
10 tied to the issue of weathering, and the number of
11 trips taking up to altitude and down is the critical
12 parameter.

13 Time was essentially not a variable in the
14 calculations I did for this here.

15 CHAIRMAN HALL: Thank you.

16 Captain?

17 CAPT. REKART: The only other question I had,
18 sir, was, Dr. Shepherd, and I believe, Dr. Baer,
19 referred to additional work to be done, and I was just
20 wondering if there was a time table for that, and how
21 much additional work you have planned?

22 CHAIRMAN HALL: That's a dangerous question
23 to ask people who are experts. I'm interested in what
24 the time frame is.

25 CAPT. REKART: Well, we are, too, since it

1 determine our workload to a certain degree.

2 CHAIRMAN HALL: Dr. Shepherd, I hope you
3 don't mind us putting you on the spot here, because I
4 didn't do it; Alpha did.

5 DR. SHEPHERD: That's what I'm paid to do, to
6 be put on the spot.

7 SO, what I would like to do, in answering
8 that, I would like to indicate first of all, kind of
9 summarize where we are at to give you a feeling of
10 where we need to go to, to give you a notion of the
11 amount of work that's involved. I'm hoping that in
12 that process, you will get some understanding of what
13 we had in mind.

14 First of all, the quarter scale program has
15 really only been underway, the actual experimentation
16 portion of that, since the middle of October with a
17 great number of breaks, or as we used to say in Upstate
18 New York, snow days. Since we're doing it in Denver,
19 we've had a lot of unusual weather this year.

20 Despite that, we had been able to do about 27
21 tests, and we have so much data now, that we're
22 completely inundated with that. We need to analyze all
23 of that data from those 27 experiments, plus the 3 more
24 that we plan to do.

25 Where we are at in this is, -- this is not

1 going to work because I'm going to have to flip this
2 around -- What we have learned so far is the rapidity
3 with which the combustion occurred once we burn the
4 ignition, and that the pressure and the time increases
5 very rapidly after an initial delay.

6 It's quite striking to see the entire
7 pressure traces. We didn't show those in those
8 comparisons, and what I would like to do is, go back
9 here a little bit and pick up some material that I
10 didn't have time to show earlier.

11 This is one of those results from an
12 experiment. This was the first test that we saw in the
13 video . This was also a test that we saw some
14 comparisons with that Mel and Kees showed, and you see
15 here six pressure traces from six transtesters.

16 Now, what you would like to do is look at
17 this data, and look at this data for experiments that
18 have been carried out with ignition and all these
19 different possible locations, understand what this data
20 tells you about pressure differences across the
21 partitions, which is what makes them move, and then
22 understanding what makes them move, come to some
23 prediction of, did they move in a way that we believe
24 they moved in the accident, as determined by the
25 sequencing group?

1 And in that way, attempt to narrow down an
2 ignition location. Now, one of the difficulties here
3 is shown by this white bar. That shows you where the
4 failure pressure is, and you can see that, and so the
5 failure would occur very early in this process.

6 so, that means that these results are not
7 terribly sensitive to the ignition location. But we do
8 believe that there is a sense to try to understand
9 that, that we have got to digest all of this data, and
10 then one of the most important parts is, we need to
11 understand how this quarter scale experiment with all
12 of its deficiencies relates to the full scale tank,
13 because this is not the actual tank; right?

14 And that's going to require a great deal of
15 work on the part of the modelers, and at this point, I
16 think Mel and Kees can say something as to the work
17 that they're going to need to do on this part of it.

18 DR. BAER: Well, certainly, we're still in a
19 validation stage in our modeling. We're not close yet
20 to the predictive at all. We've got a lot of
21 comparisons yet to do with the existing tests that have
22 been done, as well as the projected additional tests
23 that are going to be done here shortly.

24 DR. VAN WIN GERDEN: Perhaps I can add to
25 that that we also should look into how important these

1 two model the way the failure of the partitions occurs,
2 how important it is to model that accurately.

3 The experiments we assimilated with our codes
4 show that those do not agree at all, in fact, so that
5 the way the partitions fail in the experiments, and
6 possibly also in reality, is completely different from
7 what we see in our model predictions. So, it may be
8 necessary, if you want to scale up to a large scale,
9 that we describe that much better, and it's something
10 we have to look into in more detail by analyzing the
11 data in more detail.

12 CAPT. REKART: Thank you, Gentlemen.

13 Airline Pilots has no further questions, Mr.
14 Chairman.

15 CHAIRMAN HALL: You hear a date, did you,
16 Captain?

17 CAPT. REKART: No, I didn't.

18 CHAIRMAN HALL: I was afraid of that.
19 Honeywell, Inc.?

20 MR. THOMAS: Thank you, Mr. Chairman.
21 No, it's not there.

22 CHAIRMAN HALL: Are we having a microphone
23 problem? You have no questions? All right. No
24 questions from Honeywell.

25 Crane Company Hydro-Aire.

1 MR. BOUSHIE: Thank you, Mr. Chairman. Crane
2 Hydro-Aire has no questions at this time.

3 CHAIRMAN HALL: The International Association
4 of Machinists and Aerospace Workers?

5 MR. LIDDELL: Thank you, Mr. Chairman. IAM
6 has no questions at this time.

7 CHAIRMAN HALL: And Trans World Airlines,
8 Inc.?

9 MR. YOUNG: Thank you, Mr. Chairman. TWA has
10 no questions at this time.

11 CHAIRMAN HALL: Thank you, Captain.
12 Federal Aviation Administration?

13 MR. STREETER: My apologies, Mr. Chairman.
14 We do have some questions here.

15 CHAIRMAN HALL: Well, no problem.

16 MR. STREETER: Dr. Sagebiel first: In your
17 first presentations, sir, you showed a graph that had
18 three flights overlaid, and the flights were numbered,
19 and I wanted to make sure that -- I wasn't familiar
20 with the flight numbering.

21 Was one of those the flight that carried the
22 additional 12,000 pounds of fuel?

23 DR. SAGEBIEL: No, sir. I'm sorry, we did
24 not sample the flight that carried the additional fuel.

25 MR. STREETER: Okay. In that case, I would

1 like to refer then over to Dr. Bower, and find out,
2 sir, do we know whether the plane that carried the
3 additional 12,000 pounds of fuel, did it get into the
4 explosive range, or can we tell that?

5 DR. BOWER: Well, we do have the temperature
6 information.

7 MR. STREETER: Okay. Based on the
8 temperature information, did it get into the range that
9 we presumed to be explosive?

10 DR. BOWER: Well, I can display the
11 temperature information and perhaps our explosive
12 experts can have some comment on it.

13 MR. STREETER: Okay, that would help.

14 (Pause)

15 CHAIRMAN HALL: Do you have another question
16 -- oh, there we go.

17 MR. STREETER: Now, which line is the
18 additional 12,000 pounds?

19 DR. BOWER: This is the flight with
20 additional 12,000 pounds.

21 MR. STREETER: the red?

22 DR. BOWER: The red is the temperature --

23 MR. STREETER: Oh, I see.

24 DR. BOWER: -- that is immersed in fuel.

25 These temperatures down here are in the yellow in the

1 center and upper measurement locations, and the TWA 800
2 emulation flight -- I'm sorry -- the TWA 800 explosion
3 altitude is represented right here (indicating) .

4 so, we're looking at temperatures when it was
5 in the ground and in taxi of approximately 90 degrees
6 in this bay, and reduced to about 86 degrees at the
7 event altitude.

8 MR. STREETER: And that's at the upper probe,
9 is that correct, or the upper sensor?

10 DR. BOWER: Yes, upper and middle sensor, and
11 they're approximately equal.

12 MR. STREETER: And then the lower sensor
13 stays what - just below?

14 DR. BOWER: The lowest sensor, which is
15 immersed in the fuel, stays approximately 96, 98.

16 MR. STREETER: Okay, stays under 100 degrees.

17 DR. BOWER: That's correct.

18 MR. STREETER: And I'm not sure, if I can
19 refer back to the Board then, or the Panel up there,
20 since we did discuss various temperatures today, and
21 you stressed that not all of these numbers were hard
22 numbers, does that appear to have placed in the range
23 of an explosive vapor or not?

24 DR. SHEPHERD: To address that question, I
25 would like to once again return to this slide which

1 shows ignition energy as a function of temperature.
2 We're talking about a temperature of 100 degrees
3 Fahrenheit, which puts us right in this region here,
4 and we see in this region, we're talking about ignition
5 energies which are on the order of about 10 jewels.

6 I think the important consideration here is
7 that that ignition energy, although you would classify
8 this picture as flammable if you had a 10 jewel source
9 in there, that mixture is in fact 10,000 times less
10 flammable than it would be if we had no fuel in there
11 at all, in which case, the temperatures would be 140
12 degrees, and the ignition energy would be 1 millijewel.

13 MR. STREETER: Okay. And this particular
14 chart here is based on which altitude?

15 DR. SHEPHERD: This is based on the altitude
16 of 14,000 feet.

17 MR. STREETER: Okay. Thank you.

18 DR. BOWER: Dr. Shepherd, also, the
19 temperature in the ullage is actually 86 degrees, not
20 100.

21 DR. SHEPHERD: That's right, and so that's a
22 complicating factor because the temperature of the
23 fuel, and the temperature of the ullage are not the
24 same. The concentration that you get of the vapor will
25 be actually according to some temperature that's

1 intermediate to those two.

2 That probably required detailed consideration
3 of the heat and mass transfer in the tank, but you
4 would actually fall somewhat lower than that 100
5 degrees; I was just being pessimistic on that side,
6 Dan.

7 MR. STREETER: But the 86 that you're showing
8 here then is the liquid temperature?

9 DR. SHEPHERD: In our experiments, the
10 temperature is uniform. We had common temperature of
11 the liquid and the vapor. In the tank, of course, it's
12 not.

13 MR. STREETER: Understood. Thank you, sir.

14 Dr. Bower, on the flight test and
15 specifically on the test where the additional 12,000
16 pounds was carried, it is my understanding that we had
17 two AC packs running; is that correct?

18 DR. BOWER: That's correct.

19 MR. STREETER: Were they the same ones as on
20 the accident flight?

21 DR. BOWER: I don't believe they were. I
22 believe we ran packs. I'll have to check my docket on
23 that.

24 MR. STREETER: Do you recall, aside from
25 numbers, do you recall if they would have been the two

1 packs down on the left side of the aircraft, or were
2 they side-to-side.

3 DR. BOWER: Side-to-side.

4 MR. STREETER: Side-to-side. Okay, thank
5 you, sir.

6 DR. BOWER: In fact, I believe it was the
7 pack on the right, and the rear pack on the left, if
8 I'm not mistaken.

9 MR. STREETER: Okay. The right and the left
10 rear?

11 DR. BOWER: Correct; as opposed to TWA with 1
12 and 3, which were the two/four packs.

13 MR. STREETER: Again, on both the flight with
14 the additional 12,000 pounds, and on the TWA emulation
15 flight, was there any difference in the fuel that was
16 added to the center wing tank?

17 DR. BOWER: In the TWA 800 emulation flight,
18 there was no fuel added to the center wing tanks since
19 the fuel had been in there since the previous flights.
20 For the flight with the 12,000 pounds of fuel added,
21 the fuel, as was measured on the truck when it was put
22 in, was still fairly warm, and it was actually up
23 around 86 degrees.

24 MR. STREETER: Okay. About 86 on the flight
25 where we added the fuel?

1 DR. BOWER: The flight where we added the
2 fuel, and that's an approximate number. I'm trying to
3 remember that off the top of my head.

4 MR. STREETER: Okay.

5 DR. BOWER: It was in that range.

6 MR. STREETER: All right. Thank you, sir.

7 Again, to the flight with the additional
8 12,000 pounds, that one was done with, as I recall,
9 with a 90-minute ground run; is that correct?

10 DR. BOWER: That's correct.

11 MR. STREETER: As opposed to the three hours
12 on the emulation flight?

13 DR. BOWER: That's correct.

14 MR. STREETER: Okay. Have you done any
15 analysis as to what the effect would be had that same
16 flight been performed with a three-hour ground run?

17 DR. BOWER: We had a previous test where we
18 had 6,000 pounds of fuel in the tank and ran the packs
19 for a longer time; however, as I mentioned, due to
20 larger amounts of data, we're still in the process of
21 downloading and analyzing that data.

22 MR. STREETER: Okay.

23 DR. BOWER: We do have data that is
24 available.

25 MR. STREETER: Is that an answer that we

1 expect to be worked up through analysis, the effect of
2 three hours of ground time on that 12,000 pounds of
3 fuel?

4 DR. BOWER: I'm not sure I'm following you.

5 MR. STREETER: Well, I guess --

6 DR. LOEB: The answer to that is, yes.

7 Obviously, we're going to be looking at all those data,
8 analyzing all those data and making them available.

9 MR. STREETER: That's fine. Thank you.

10 And now for this, I'm not sure if this would
11 be Dr. Bower or Dr. Birky:

12 When the additional wiring was added to the
13 airplane prior to the testing, I believe there was a --
14 well, I shouldn't say "I believe" -- was there a
15 failure modes and effect analysis done on that
16 installation?

17 DR. BIRKY: The Boeing staff did that work,
18 and, yes, there was.

19 MR. STREETER: Okay. Did the findings of
20 that analysis require any changes in operational
21 procedures that would have made anything significantly
22 different from TWA's normal procedures?

23 DR. BIRKY: Not that I'm aware of.

24 DR. BOWER: None that I'm aware of either.

25 MR. STREETER: Okay. Thank you.

1 Dr. Shepherd, please, on your quarter scale
2 tank testing, you gave what I thought was a good
3 explanation of how you worked some of the weakened
4 panels in there, but the way I see the tank set up, I
5 want to make sure I have it right. It doesn't simulate
6 any of the bulging of the upper and lower surfaces; is
7 that correct?

8 DR. SHEPHERD: The panels are held in by a
9 set of screws, seven on the top, and seven on the
10 bottom. I don't have a detail of the panel here that I
11 can show you. What I can show you is what those panels
12 looked like when they come out of that tank, and I'd
13 like to do that right now.

14 Now, if you look closely at this, and I will
15 help you out by putting a pointer on here, there are
16 two panels that are wrapped around the post that we
17 used to catch the panels so that they wouldn't break off
18 some pressure gauges we had further on.

19 Those two panels are, of course, the front
20 bar and spanwise beam 3. This is a test that was done
21 without any liquid jet fuel in the bottom of the tank,
22 so we could see what was happening with the panels, and
23 that would be the spanwise beam 2. That would be the
24 mid spar, and that's spanwise 1.

25 Now, you can see these come out in all

1 different shapes and different amounts of deformation,
2 which are due to the way in which they are torn out of
3 the tank, and some of them are bent and twisted and are
4 quite marked, and others appear to be relatively
5 intact .

6 so, there is in fact bulging if you look at
7 some of the high speed of movies that we have where we
8 look through the sides, we can see through the sides
9 here, the sides of the tank I'm pointing to with my
10 little pointer, and when we actually see the panels
11 begin to fail, you can see them bulge.

12 MR. STREETER: Now, is that bulging on the
13 failed panels, or on the upper and lower --

14 DR. SHEPHERD: The way we constructed this,
15 we had to make some design choices in order to be able
16 to re-use this facility, and so the top, this portion,
17 and the bottom and the back are constructed on a three-
18 quarter inch steel, which in addition, you can see
19 there is about a 10-inch structure eye beam, and then
20 mounted across, running across are more structural eye
21 beams.

22 so, that part of the structure is in fact
23 designed to withstand the 100 psi over-pressure. So,
24 in that way, it does not model the response of the
25 actual time. That's one of the many ways it fails to

1 model . This was not designed to be a structural model,
2 by any means.

3 The reason why we put the failing panels in
4 there was really to look at how the panel failure would
5 affect the combustion, not to see the panel failure
6 itself.

7 MR. STREETER: All right. Understood, sir.

8 Given the fact that the one element of the
9 sequencing groups work appears to be that there was
10 some - I think it's safe to say - significant bulging
11 of the upper and lower surfaces in the tank for the
12 entire panel, because I don't know which one would be
13 appropriate, is that something that's possible to model
14 in the future work?

15 DR. SHEPHERD: First of all, it's something
16 that we obviously are not modeling right now. In
17 principle, there are things that are difficult. Some
18 of the combustion aspects are difficult. Modeling the
19 structural response, if we really have a good
20 characterization of the real system, in other words,
21 that we know exactly what was there, in principle, that
22 is not usually difficult.

23 It's a matter of taking a structural response
24 code of which anybody in the airline industry here are
25 familiar with, so I won't bother explaining that; and

1 coupling it to the CFD codes, it is more a matter of
2 the labor of doing that and making sure that the
3 algorithms are correct.

4 so, in principle, yes, it is possible to do.

5 MR. STREETER: Do you know yet whether there
6 are plans to do that?

7 DR. LOEB: Let me try to deal with this, if I
8 can. The answer is, yes, we're going to do everything
9 we can to couple eventually the structural modeling as
10 well. Ultimately, we may in fact carry out full-scale
11 testing on one or two tanks to see and to try to
12 validate against the structural modeling, as well.

13 We're not there yet. We have a long way to
14 go to complete these tests, but there was no attempt -
15 and I think it's important to understand what Dr.
16 Shepherd - there was no attempt to replicate
17 structurally. That's for the future.

18 MR. STREETER: Okay. Thank you, Dr. Loeb,
19 and that also answered my last question which was about
20 full-scale testing.

21 That's all I have, sir.

22 CHAIRMAN HALL: Thank you very much.

23 Do any of the parties have any questions that
24 you have not had an opportunity to ask this particular
25 panel?

1 (No response)

2 CHAIRMAN HALL: If not, does the Technical
3 Panel have any additional questions?

4 DR. BIRKY: Well, I don't have any additional
5 questions, but I would like to make one other comment,
6 if I may, Mr. Chairman.

7 We relied fairly heavily on Boeing for these
8 flight tests and the work they did, they get that
9 aircraft instrument, and I would like to recognize them
10 for that effort.

11 CHAIRMAN HALL: Well, the Chairman also
12 appreciates that. I went up to New York. I got on the
13 Evergreen plane and I saw all the work that had gone
14 into doing the instrumentation, and, of course, I noted
15 the comment about the failure analysis, because I had
16 to ask the question, well, if you're re-simulating TWA
17 Flight 800, how are you going to be sure that you don't
18 have the same result?

19 so, I thank Boeing for your assistance on
20 that. Obviously, you all provided a whole lot of very
21 important technical assistance in that test.

22 MR. SWEEDLER: Thank you, Mr. Chairman.

23 CHAIRMAN HALL: I guess we will move into the
24 Board of Inquiry.

25 Mr. Sweedler?

1 MR. SWEEDLER: I have no questions, Mr.
2 Chairman.

3 CHAIRMAN HALL: Dr. Ellingstad?

4 MR. ELLINGSTAD: Just one question for, I
5 believe, Dr. Bower and perhaps Dr. Shepherd:

6 I understand with respect to the flight test
7 that this is a relatively unique data collection
8 activity that was conducted. Dr. Sagebiel mentioned
9 that he was not aware of previous attempts to do any
10 vapor sampling.

11 Are yo aware of any other flight tests that
12 have gathered these kinds of data?

13 DR. BOWER: I'm aware of only the one
14 previous test done by Boeing in the Majuave Desert in
15 August '96, I believe. Aside from that, I know of none
16 other.

17 MR. ELLINGSTAD: Are there other similar
18 kinds of measurements that you see a need to do to more
19 fully understand the environment in the center wing
20 tank?

21 DR. BOWER: Yes, I believe so. We got a lot
22 of interesting data in the flight test which often
23 happens in an experimental program. It just opens up
24 the door for more questions.

25 I saw a lot of warm temperatures underneath

1 that center wing tank in the air-conditioning pack bay.
2 You see a lot of warm temperatures in some of the
3 components, which brings the question: How can we ever
4 keep those warm temperatures from reaching the tank,
5 increase the ullage temperatures, increase the
6 flammability?

7 In order to make that happen, one of the ways
8 to keep that heat from happening, so it's good to
9 quantify how that heat is going from those packs to the
10 center wing tank. Additional measurements within that
11 pack bay, measuring the types of fuel transfer that is
12 occurring from those pack components to the center wing
13 tank; measuring the rate of heat transfer versus
14 effective heat transfer.

15 Those type of measurements would be
16 effective, and perhaps some additional verification on
17 the acceleration measurements and also be warranted.

18 MR. ELLINGSTAD: Thank you, Dr. Bower.

19 CHAIRMAN HALL: Dr. Loeb?

20 (No response)

21 CHAIRMAN HALL: I just have one question, and
22 I don't believe we got into the subject of the anti-
23 static additive that is used in Europe but is not used
24 in the United States in the fuel, and whether that had
25 any impact on any of the tests, or how that was

1 considered in your work?

2 DR. SHEPHERD: Mr. Chairman, we did not
3 examine any fuels other than the Athens fuel. I
4 presume that the Athens fuel does have some anti-static
5 additive to it. There is the additional complication
6 that the Athens fuel that we have, of course, was
7 handled a number of times. It corresponds to the
8 samples that we used in the flight test.

9 If it was desirable to have an understanding
10 of how that affects ignition, that is something that
11 could be perceived, but we have not done that at this
12 time.

13 CHAIRMAN HALL: Kees, do you know why that is
14 added in Europe and not done here? Does FAA know why
15 the anti-static additive is in the European jet fuel,
16 and not here?

17 DR. VAN WIN GERDEN: I'm not aware of the
18 reason why.

19 CHAIRMAN HALL: Well, they told me they're
20 going to get into that tomorrow, so I'm jumping the
21 gun. Okay.

22 Well, I don't have any other questions. I
23 just appreciate this Panel. As I said before, we have
24 tried to put together some experts that can help us
25 find out what caused this center tank to explode, what

1 the ignition source was so the families would know, the
2 American people would know, and we could fix it.

3 We have some very distinguished individuals
4 here, and I hope that they feel free at any point, and
5 any of the parties feel free, that if there are other
6 people that need to be added to the group or other
7 things that need to be done, that you would let us
8 know, because we're going to stay after this.

9 But I'd like to close. Are there any
10 comments you would want to share before we close?

11 DR. SHEPHERD: No, sir. I would just like
12 to thank everyone here on the Panel today.

13 CHAIRMAN HALL: Dr. Sagebiel?

14 DR. SAGEBIEL: No, sir.

15 CHAIRMAN HALL: Dr. Thibault?

16 DR. THIBAULT: No, sir.

17 CHAIRMAN HALL: Dr. Baer?

18 DR. BAER: No, sir.

19 CHAIRMAN HALL: Dr. Kees?

20 DR. VAN WIN GERDEN: No, sir.

21 CHAIRMAN HALL: Mr. Woodrow?

22 MR. WOODROW: No, sir.

23 CHAIRMAN HALL: Well, let me just remind the
24 expect panel that you are spending a lot of the
25 American tax dollars on these experiments, and we

1 certainly hope that you will proceed with due haste, as
2 you have in the past.

3 We have the international laboratories. We
4 have the international group from Norway. We have CAL
5 Tech. We have an outstanding group of people, and I
6 had an opportunity to spend several hours with you all
7 in Denver, and even though we are trying to reimburse
8 you for this work, I was impressed by the personal
9 commitment that each one of you brought to this effort,
10 and I want to thank you.

11 Very well. That concludes this discussion on
12 the Flammability Panel. We will begin tomorrow with
13 the Ignition Source Panel, and we will start promptly
14 at 9 a.m. We stand in recess.

15 (Whereupon, at 7:19 p.m., hearing in the
16 above-entitled matter was adjourned, to reconvene on
17 Wednesday, December 10, 1997, at 9:00 a.m.)

18
19