

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

DR. BERNARD LOEB, Director

Office of Aviation Safety

BARRY SWEEDLER, Director

Office of Safety Recommendations  
and Accomplishments

DAN CAMPBELL, General Counsel

TECHNICAL PANEL:

THOMAS HAUETER, Chief

Major Investigations Division

AL DICKINSON, Investigator-in-Charge  
Operations

GEORGE ANDERSON

DR. MERRITT BIRKY

DR. DAN BOWER

MALCOLM BRENNER

JOHN CLARK

DENNIS CRIDER

DEBRA ECKROTE

MITCHELL GARBER

FRANK HILLDRUP

HENRY HUGHES

## TECHNICAL PANEL (Cent'd) :

LARRY JACKSON

DEEPAK JOSHI

DAVID MAYER

CHARLES PEREIRA

ROBERT SWAIM

BURT SIMON

DOUG WIEGMAN

NORMAN WIEMEYER

JAMES WILDEY

## PARTIES TO THE HEARING:

On Behalf of Federal Aviation Administration

LYLE K. STREETER, Air Safety Investigator

800 Independent Avenue, S. W.

Accident Investigation Division, AA1-100

Washington, D. C. 20591

On Behalf of Union:

FRED LIDDELL, Coordinator

District Lodge 142, IAMAW, AFL-CIO

400 N. E. Thirty-Second Street

Kansas City, Missouri 64116

## PARTIES TO THE HEARING (Cent'd) :

## On Behalf of Boeing:

J. DENNIS RODRIGUES, Air Safety Investigator  
Boeing Commercial Airplane Group  
P. O. BOX 3707 MS 67-PR  
Seattle, Washington 98124-2207

## On Behalf of TWA:

ROBERT YOUNG, Director  
Flight Operations Safety  
Trans World Airlines, Inc.  
Flight Operations Training Center  
11495 Natural Bridge Road  
Bridgeton, Missouri 63044

## On Behalf of Honeywell:

HAL THOMAS, Staff Engineer  
Air Transport Systems  
Box 21111  
Phoenix, Arizona 83036

PARTIES TO THE HEARING (Cent'd) :

On Behalf of Crane Co.

RAYMOND W. BOUSHIE, President

Crane Hydro-Aire

A Subsidiary of Crane Co.

3000 Winona Avenue

P. O. BOX 7722

Burbank, California 91510

On Behalf of Air Line Pilots Association, Int'l.

MICHAEL HUHN, Staff Engineer

Engineering/Accident Investigation Section

535 Herndon Parkway

P. O. BOX 1169

Herndon, Virginia 22070

## I N D E X

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## I N D E X

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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

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

18

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

23

Since then, we built systems for most of the  
24 major aircraft manufacturers in the U. S. We went to  
25 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 to 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 CO<sub>2</sub>,  
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 naphtha 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. THIBAUT: 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.)

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