BEFORE THE

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D. C.

- x
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 :
- x

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

Tuesday, December 9, 1997

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

BOARD OF INQUIRY:

HONORABLE JIM HALL, Chairman
Member of NTSB
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Office of Aviation Safety
BARRY SWEEDLER, Director
Office of Safety Recommendations
and Accomplishments
DAN CAMPBELL, General Counsel

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THOMAS HAUETER, Chief
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
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FRANK HILLDRUP
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TECHNICAL PANEL (Cont'd):

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DAVID MAYER

CHARLES PEREIRA

ROBERT SWAIM

BURT SIMON

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P R O C E E D I N G S

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

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

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

(No response)

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

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

MR. DICKINSON: Good morning, Mr. Chairman.

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

(Witness testimony continues on the next page.)

Whereupon,

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

were called as witnesses 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.

The Fuel Tank Design Philosophy and Certification Panel --

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

Thank you very much.

Please proceed.

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

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

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

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

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

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

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

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

Jerry Hulm, who is the Manager of Electrical Systems with Boeing Commercial Airplane Group, and I would appreciate it -- well, I guess you have your name tags up there, but please raise your hand, just so the audience knows you.

(Mr. Hulm raised his hand)

MR. DICKINSON: Thank you.

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

Next is Mr. Ron Hinderberger.

(Mr. Ron Hinderberger raised his hand)

MR. DICKINSON: Thank you.

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

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

Daniel Cheney.

(Mr. Dan Cheney raised his hand)

MR. DICKINSON: Thank you.

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

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

Chris Hartonas.

(Mr. Chris Hastonas raised his hand)

MR. DICKINSON: Thank you.

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

Beatris Rodriguez.

(Mr. Beatris Rodriguez raised her hand)

MR. DICKINSON: Thank you.

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

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

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

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

(Mr. Lou Taylor raised his hand)

MR. DICKINSON: Thank you.

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

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

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

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

CHAIRMAN HALL: Please proceed.

BOB SWAIM

Introductory Briefing

MR. SWAIM: Thank you, sir.

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

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

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

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

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

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

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

WITNESS CHENEY: Yes, Bob.

DAN CHENEY, FAA

Certification Requirements for Volatile Vapors in Fuel Systems

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

We know that that is not always the case, but for the purposes of the safety evaluation, we have assumed that it is always flammable, and that's been essentially the basis of aviation since the first airplane.

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

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

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

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

Two years after that, the Boeing Company applied for type certification for the 747. So, the involvement of the development of standards for lightning were superimposed upon the evolution and the certification of this airplane. The policies that were developed were actually applied initially to this 747 airplane.

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

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

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

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

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

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

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

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

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

The Advisory Circular was also issued at about that same time, that also describes the criteria by which you ultimately determine explosion-proofness.

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

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

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

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

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

WITNESS CHENEY: Well, the regulations are a process that the people have a great hand in developing, and there is not any regulation that isn't put forward for full public debate, full public comment.

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

MR. SWAIM: Okay. Thank you.

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

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

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

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

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

IVOR THOMAS, Boeing

Fuel Tank Safety

(Slide)

WITNESS THOMAS: The first slide is a very simple system that I designed.

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

WITNESS THOMAS: Okay. Excuse me.

CHAIRMAN HALL: -- for everybody to hear well.

WITNESS THOMAS: Is that better?

CHAIRMAN HALL: That's fine.

WITNESS THOMAS: Thank you.

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

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

So, we addressed both sides, both the ignition, preventing ignitions in the airplane, and providing a highly reliable system.

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

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

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

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

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

WITNESS THOMAS: Correct; surface temperature, yes.

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

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

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

We refer to that as an auto ignition temperature, or octagenous ignition temperature. We measure the surface temperature and say when that will happen. It's a function of the size of the tank. It's a function of the surface area, the temperature of the surface are. The testing has been done. Certainly, I'm aware of going back 30 and 40 years, has established a minimum number of 445, 450 degrees as the lowest number you can achieve ignition at, and that's in a very carefully controlled experiment.

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

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

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

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

WITNESS THOMAS: Well, the flammability range is ordered by a temperature below which the vapor is too lean to burn, and on the upper send, too rich to burn. And those are referred to as the lean limit and the rich limit; and for kerosene, Jet A fuel at standard pressure, that lean limit is approximately 100 degrees Fahrenheit.

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

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

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

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

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

CHAIRMAN HALL: Micro what?

WITNESS HINDERBERGER: Microjewels.

CHAIRMAN HALL: Microjewels. All right. Thank you.

Mr. Thomas?

WITNESS THOMAS: Certainly. Does that satisfy your questions?

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

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

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

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

WITNESS THOMAS: Any of our surface temperatures inside the fuel tank, we would keep below the 390 degree number, and that is in a failure case, as well. That is not normal running typically of the equipment; we are running much, much, more cooler than that. But in a failure case, we design it to make sure we do not exceed that 390 degrees Fahrenheit.

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

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

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

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

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

CHAIRMAN HALL: And in the Sixties, was that based on Jet A fuel, or was that based on another fuel, or was the fuel unimportant to that?

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

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

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

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

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

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

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

DR. BIRKY: Okay. But I'd like to go back to this question of explosion-proof. Are you suggesting that the FAR 25.981 does not refer to explosion-proof, or it does? I'm not sure.

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

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

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

WITNESS CHENEY: That's correct.

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

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

DR. LOEB: Okay. Thank you.

MR. SWAIM: That then would not refer to, say, the bottom of the fuel tank located above the air-conditioning machinery?

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

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

WITNESS CHENEY: Yes.

MR. SWAIM: Okay.

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

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

DR. LOEB: But it is not a requirement?

WITNESS CHENEY: It's not a requirement.

CHAIRMAN HALL: Please proceed, Mr. Thomas.

WITNESS CHENEY: Thank you, sir.

CHAIRMAN HALL: And if you will just indulge us on this because this is an important area, and I want to be sure that all understand it, those at the top of the expert level, and those who are just down where I am.

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

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

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

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

WITNESS THOMAS: Excuse me. A latent failure is a failure that is not obvious, but in the performance of the airplane if something occurs in the sense of, it is not detected, and therefore, can be present in the airplane at length, it would show up in a maintenance activity later on.

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

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

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

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

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

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

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

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

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

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

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

MR. SWAIM: From something that Mr. Thomas brought up on temperatures, I have a question. Back to Mr. Cheney: For the tape temperatures, you were referring to a maximum temperature that you would permit.

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

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

MR. SWAIM: Okay.

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

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

WITNESS THOMAS: Let me continue.

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

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

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

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

When you pull the fire handle, both of those signals drive the valve to a closed position. The override pumps in the center wing tank, we talk about override pumps as being equipment in the center tank. Those pumps are designed to provide fuel to the engine when you are burning fuel from the center wing tank.

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

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

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

There is a cross feed valve in the middle of the airplane that allows you to feed fuel from one side to another, first of all, to balance the airplane. If one engine is using fuel slightly more than the other one, you can open the cross revalve and balance the airplane that way, feed fuel from one side across the airplane to the other engine to balance the airplane.

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

You can go to the next one.

(Slide)

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

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

The motor that drives that impeller is contained in a chamber unto itself, and the design of that is to make sure that that chamber is explosion-proof. We have used the term "explosive-proof." This is a chamber where the motor is setting, but it's designed specifically. If there was an electrical failure in the motor that could ignite the fuel vapor in that chamber, the explosion itself is contained. The chamber is strong enough to contain the explosion.

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

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

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

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

CHAIRMAN HALL: What's the lowest?

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

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

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

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

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

You can go to the next slide, Derrick.

(Slide)

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

If the pump fails for whatever reason, the pressure will drop. The light comes on. The crew knows about it immediately. Or if the circuit breaker pops, the light will come on, and the crew knows about it immediately.

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

The next slide, Derrick.

(Slide)

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

In actuality, in the Boeing practice, we use vent stringers, actually specific structural members inside the fuel tank to provide those by passageway. The fuel vent system allows the tank to breathe as the airplane climbs and dives. We try to keep the tank close to atmospheric pressure, so as the pressure in the atmosphere, we need to vent air in and out. We do that through the vent system.

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

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

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

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

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

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

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

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

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

WITNESS THOMAS: I think there are at least two or three of us on the panel here. A DER is a Designated Engineering Representative of the FAA. It is an employee of, in this case, if I speak about myself as a DER, I'm an employee of the Boeing Company. The FAA, through exposure to myself when I go down and discuss issues with the FAA, get to the point where they feel they can trust me and rely on my judgment.

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

CHAIRMAN HALL: I appreciate that explanation.

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

We have something like 1,000 engineers who do nothing but monitor traffic, communication traffic, between ourselves the airlines. We have engineers out with all the major airlines all over the world. Any kind of problem, it is reported back, gets looked at very quickly and very carefully to say if it's a safety issue, or is it just another small problem that we don't have to worry about. We can go fix for the airlines in an economic fashion as opposed to a safety fashion.

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

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

That concludes my presentation part of this.

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

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

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

WITNESS HINDERBERGER: Yes, Mr. Swaim.

RON HINDERBERGER, Douglas

Certification Process

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

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

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

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

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

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

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

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

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

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

MR. SWAIM: Of course.

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

WITNESS HINDERBERGER: Chairman Hall, it was one basic design philosophy, and it was looked at from a standpoint that what we would do is, assume that there is a flammable mixture at all times. If you assume there is a flammable mixture at all times, then you must also preclude a spark from occurring at all times.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

WITNESS THOMAS: That's correct.

CHAIRMAN HALL: Okay.

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

WITNESS THOMAS: There are issues. I'm not sure I can categorize them as problems. There are questions that we need to resolve. Again, it's going to a higher flash point fuel like the JP-5 kinds of fuel, you have to worry about all the properties of the fuel.

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

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

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

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

Ms. Rodriguez, thank you.

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

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

Yes?

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

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

So, basically, once we start having problems with our freezing points below 40 degrees for pump performance, so the Navy uses JP-A on land bases, so the Navy people will have a mixture. Their aircraft is using JP-5 in carrier, and land using JP-A. Basically, JP-A is a common fuel for only military aircraft.

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

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

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

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

WITNESS THOMAS: As far as the Philippines 737 accident, we spent a large amount of time looking at potential ignition sources. There was no ignition source established to cause that accident. We spent a lot of time and energy looking at -- I think we looked at well over 70 different potential ignition sources.

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

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

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

WITNESS THOMAS: That is correct.

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

WITNESS HINDERBERGER: No, sir, Dr. Loeb, we did not.

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

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

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

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

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

WITNESS CHENEY: And I think, as the Administrator mentioned in the letter the other day to the Board, we are agreeing with the Board that it is very appropriate to very much explore reducing or eliminating flammable vapors in tanks.

DR. LOEB: Good. Thanks.

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

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

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

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

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

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

WITNESS THOMAS: I would certainly try.

CHAIRMAN HALL: I would appreciate it.

I was very interested in what Boeing has done because I know you have done quite a bit, and I would like on the public record for the public to know what Boeing has done.

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

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

DR. BIRKY: I'm sorry.

CHAIRMAN HALL: Please proceed, Mr. Thomas.

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

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

We looked at alternatives. We took the opportunity when the NTSB was flying the Evergreen airplane to fly additional flight tests on that airplane, both to look at the effect of, could we do some kind of pack bay cooling.

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

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

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

And that is why we occasionally appear to be slow, but we would much prefer to be slow and careful and correct than rushing into something, and then we find out six months later, it was the wrong thing to do.

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

WITNESS THOMAS: That, we are doing, sir.

CHAIRMAN HALL: I appreciate that.

Dr. Birky, I'm sorry.

DR. BIRKY: My apologies, sir.

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

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

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

We put out flight operations instructions to the airlines to remind them that we should not be running the pumps dry for a long time, even though we qualified that the pumps would be able to run dry. There is no reason to do so when the tank has no fuel in it. And we put out those instructions.

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

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

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

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

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

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

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

CHAIRMAN HALL: But, I guess again, I go back to the FAA, and if you accept this philosophy, and I know that in the late Sixties, I was in the Military, and I don't know whether you all were with FAA and Boeing at the time, but I know this was done in the late Sixties, but someone said, "We're going to certify these aircraft. We're going to make the assumption that the fuel tank is flammable, and we're going to engineer out the ignition sources."

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

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

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

I would like to --

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

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

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

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

CHAIRMAN HALL: So what happened with the Philippines 737?

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

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

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

CHAIRMAN HALL: Thank you.

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

MR. SWAIM: Thank you, sir.

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

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

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

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

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

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

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

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

On the DC-10 the nearest intersection of all the pneumatic systems would indeed be in the center wing tank area. What occurred on the DC-10 as the air-conditioning packs were being designed is, the size of the air-conditioning packs was larger than the available space between the center wing tank and the faring that runs between the wing and the fuselage.

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

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

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

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

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

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

WITNESS HINDERBERGER: That's correct.

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

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

BEATRIS RODRIGUEZ, USAF

Military Fuel Systems

MS. RODRIGUEZ: As part of the Air Force aircraft fuel certification process, the Air Force requires a verification and validation test plan for functional and performance requirements. The verification and validation test plan is developed working with the contractor. We required extensive analysis, inspection, demonstration during ground and flight tests.

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

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

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

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

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

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

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

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

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

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

MS. RODRIGUEZ: One thing I could mention is, we are constantly buying derivatives from commercial airplanes. We do buy FAA's certified aircraft, and we make modification to those aircraft based on Air Force mission. Most of the time in the fuel system area, some of those modifications have to do with air refueling mission that's a mission requirement for that particular aircraft.

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

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

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

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

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

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

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

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

MR. SWAIM: Mr. Chairman?

CHAIRMAN HALL: I'm sorry.

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

CHAIRMAN HALL: I'd love to hear it.

MR. SWAIM: Okay.

LOU TAYLOR, Honeywell

Fuel Quantity Indication System

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

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

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

Since then, we built systems for most of the major aircraft manufacturers in the U. S. We went to the Boeing 377 Strata Cruiser, the Boeing 707 and 720, the 747 Classic that we're doing with here; the 57 and 67. Douglas Aircraft included DC-6, DC-7 and DC-8. There are various Military applications, and we also have built liquid fuel measurement systems for various spacecraft.

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

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

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

On the flight engineer's panel, you have the fuel quantity indicator, and this is one of the fuel quantity indicators. This is an indicator from the center tank. You have one indicator per-tank. Also on the flight engineer's panel, you have a fuel totalizer. This is one of the totalizers which shows the total field quantity, and it also shows the total aircraft gross weight.

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

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

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

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

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

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

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

MR. SWAIM: Thank you.

WITNESS TAYLOR: I mentioned this is a capacitive type system. I will give you a description of what a capacitive type system is. The indicator is what's known as a rebalance ridge type indicator. The tank units - we have a shorter one here that's a little easier to talk to, and each section is open so you can see the inside - we operate these at a fixed voltage, and the capacitance of the tank changes. So, we're using this as a variable capacitor.

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

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

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

If they're slightly out of balance, we create a rebalance signal, and it's a very, very small signal. We run that through an amplifier, and the amplifier runs a small motor inside the indicator, and we take a look at that, and that motor will change the indication on the face, so you move the dial. It also moves the variable resistor. It's a ten turn precision for the potentiometer, and that adjusts the voltage going back to the compensator. So, it's really a very simple basic system. It balances against each other if there is any slight imbalance. It automatically adjusts and mechanically does both the potentiometer and the indicator at the same time.

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

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

The totalizer we mentioned, is also up in the flight engine of your panel. It's connected to each one of the indicators, and it will take the fuel indication from each of the indicators and add it up. In this case, it's showing 298,000 pounds of the total fuel. At the beginning of the flight, the flight engineer can set the gross weight of the aircraft for this particular flight. In this case, it says 648,000 pounds.

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

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

The inner element is electrolysis nickel, and you can see on the diagram here that it changes diameters. If the fuel tank was just a pure square rectangular box, this would be a straight tube. But the fuel tank is not regular shaped. There are various other pieces in there, and as you go up vertically in height, what we're doing is, changing the diameter of the inner element, and that means that the capacitance will change directly with change in fuel quantity.

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

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

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

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

The volumetric shut off, as I said, takes the indication from each of the fuel quantity indicators. The fuel quantity indicators is telling you the mass of fuel, the number of pounds of fuel you've got on board, and the engine creates energy based on the mass of fuel.

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

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

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

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

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

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

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

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

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

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

WITNESS TAYLOR: That's correct.

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

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

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

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

DR. LOEB: Okay. Thank you.

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

DR. LOEB: Thank you.

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

CHAIRMAN HALL: What type of wiring do you use?

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

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

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

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

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

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

WITNESS TAYLOR: I know that the in tank

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

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

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

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

MR. HULM: Yes. The test conditions that we're looking at here with the 1,500 volt AC test and the inflation resistance test, those are basically still the same things we use today. The wiring has changed and the technology has changed. Some improvements have been made in the wiring itself as far as the characteristics as the installation, its weight and cost, and things like that.

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

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

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

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

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

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

WITNESS TAYLOR: Those are the same tests.

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

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

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

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

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

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

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

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

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

What we wound up with, so we took my pager, and my pager sitting here right now in its normal passive system, it draws about 1-1/2 milliamps, or it draws five times the current that the fuel quantity system draws in a normal operation. When my pager goes off, it draws about 45 milliamps, or between four and five times our current limit.

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

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

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

WITNESS TAYLOR: At a full tank, they run to approximately 25 volts. One of the things we did also to try and put this in perspective, you can hang onto the wiring and you don't feel a thing. You have no idea if this is on or off if you're holding the wires. So, this is an extremely low energy system.

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

Thank you.

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

(Whereupon, a brief recess was taken.)

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

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

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

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

Taylor's presentation.

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

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

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

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

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

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

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

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

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

CHAIRMAN HALL: How long would those probes last?

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

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

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

MR. SWAIM: Mr. Taylor, are those probes in that system, since you make systems for the different manufacturers, are those systems given by the manufacturers as requirements? I know prior to the 747, you were building fiberglass fuel probes; or do those truly come from Honeywell, the requirements for how we're going to design a fuel probe system?

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

MR. SWAIM: Okay.

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

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

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

CHAIRMAN HALL: How often is that testing done?

MS. RODRIGUEZ: It depends on the specific aircraft. I will have to go to that particular tech order and tell you exactly. I don't have a specific kind.

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

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

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

MR. SWEEDLER: How about inspecting them?

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

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

WITNESS HARTONAS: The same applies.

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

WITNESS TAYLOR: There have been no

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

CHAIRMAN HALL: Could you briefly describe those for us?

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

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

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

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

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

CHAIRMAN HALL: Electrical problem?

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

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

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

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

MR. SWAIM: Okay. Thank you.

This is a photograph. It's a little burned out. The photo in the lower left, the illustration, these are wires that would be going between the cockpit and the computer that you're showing that you had up on the table, and the pointed in the very center of the photo is to a wiring bundle that would carry the signal to that computer.

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

Mr. Taylor, I'm sorry.

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

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

MR. SWAIM: The air gap?

WITNESS TAYLOR: Downstream.

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

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

MR. HULM: I don't know the direct answer to that question. We have looked at it, and since a spec was written, and we have not been able to figure out exactly -- there are two possible reasons why that was in there. One was if somebody did actually grab that wire and pull on it, that the wire at the 50-pound limit would break and prevent damage then to the terminals themself, or it was just to demonstrate that if you did pull on it, it would stand up to 50 pounds without damaging the probe.

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

MR. SWAIM: Very good. I appreciate it.

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

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

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

WITNESS TAYLOR: None that we're aware of.

MR. SWAIM: Okay. Thank you.

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

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

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

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

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

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

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

DR. LOEB: Excuse me, Bob. Is it possible, Mr. Hulm, that you could explain what Boeing did to address the issue of the potential for ignition sources and engineering out the ignition sources, what they did at the time that this tank was done, and what you would do today, and maybe that would put this whole thing in perspective?

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

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

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

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

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

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

There are other instances, though, where you can imagine a lot of things as far as failing in the system, and we try to evaluate to make our best engineering judgment on what we think are likely failures, and what are not so likely; and we look at combinations of these failures, and as far as what we think could or could not happen on an airplane, and try to bring it back into reality.

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

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

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

MR. HULM: The failure modes, or each individual instance that occurred, is really based on the design and what the environment of the equipment was installed in. So, in the case of a fuel tank, when we look at that, we determine what the equipment is subjected to, and what kind of failures we have seen from service history, from previous designs we experienced on other airplanes, and we look at that in relation to how the current system that is being designed.

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

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

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

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

MR. HULM: Well, you know, in the particular instance of the structural damage, we have to make a little bit of a judgment when we're looking at the data returned from the airlines and what is returned to Honeywell as far as what they are repairing, and something called structural damage itself may be a simple dent in the probe that results in a minor fuel quantity indication. It doesn't necessarily mean that the probe was destroyed or that it fell off or broke or anything; it just means that it was removed from the airplane due to some sort of external damage to it.

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

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

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

DR. LOEB: The problem is that we are

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

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

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

MR. HULM: For the --

CHAIRMAN HALL: Failure of the tank?

MR. HULM: The structural part?

CHAIRMAN HALL: Yes.

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

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

So, there is no failure mode per se.

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

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

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

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

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

CHAIRMAN HALL: The boost pumps are explosion-proof?

WITNESS THOMAS: Right.

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

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

CHAIRMAN HALL: Yes.

WITNESS THOMAS: Oh. Excuse me.

CHAIRMAN HALL: And you look at the failure.

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

WITNESS THOMAS: Correct. We had this one.

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

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

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

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

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

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

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

CHAIRMAN HALL: Thank you.

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

Are there differences in design or the

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

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

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

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

WITNESS THOMAS: Including failures, we design the system so that if the system fails on the engine, we have sensors that step in and control and shut down the system if the temperature goes over 500 degrees. So, we have a built-in protection feature to make sure we do not exceed that 450 degree number.

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

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

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

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

There is an industry group that has been formed, and their intent has been announced, but it's composed of over 60 airlines and air associations, all the major aircraft manufacturers, including Boeing, Lockheed and Air Bus, and the purpose of this industry working group is to put together an extensive inspection program to assess the condition of fuel tanks, not just center tanks on these airplanes, but also the main tanks.

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

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

MR. HULM: Correct.

DR. LOEB: That's because of what?

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

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

MR. HULM: Correct.

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

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

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

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

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

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

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

DR. BIRKY: But does that mean you are or are not participating in the special inspection program with the industry?

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

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

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

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

Mr. Cheney?

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

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

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

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

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

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

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

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

MR. SWAIM: So, are you saying that you had measured the temperatures at the tank previously? You knew what the temperatures were coming out, and therefore, knew that they were dropping to get to that indicator going into the engine?

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

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

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

As Mr. Cheney said, the issue here is not whether the center tank was flammable; it is a function of, is the fuel hot enough to run into captation problems and disrupt engine feed. The notes in the flight manual are really intended to provide advice and guidance to the crew that the center tank fuel itself may be warmer than the fuel in the wing tanks.

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

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

MR. SWAIM: Please.

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

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

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

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

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

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

CHAIRMAN HALL: Which is?

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

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

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

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

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

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

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

CHAIRMAN HALL: Are you inspecting all the classics?

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

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

WITNESS CHENEY: That covers the entire 747 fleet.

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

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

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

WITNESS CHENEY: I don't know the answer to that question.

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

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

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

CHAIRMAN HALL: Excuse me, Dr. Loeb.

Are any 747s being inspected as we're sitting here today, or not?

WITNESS CHENEY: Yes, sir, they are.

CHAIRMAN HALL: Can you tell us which ones?

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

CHAIRMAN HALL: Part of the service bulletin?

WITNESS CHENEY: For the service bulletin.

CHAIRMAN HALL: Into the tank?

WITNESS CHENEY: Into the tank.

CHAIRMAN HALL: Fifty-two of 970?

WITNESS CHENEY: Correct.

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

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

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

WITNESS CHENEY: Yes, I could.

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

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

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

WITNESS CHENEY: Correct.

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

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

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

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

WITNESS CHENEY: I believe there's approximately 750.

CHAIRMAN HALL: Of the 970?

WITNESS CHENEY: Correct.

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

WITNESS CHENEY: Correct.

CHAIRMAN HALL: Okay.

Please proceed.

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

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

DR. BIRKY: How about on the fuel probes?

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

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

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

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

So, what is the process? Are you waiting until a recommendation, the service bulletin comes out, to consider it? Are you with your DERs involved in that process so if it was a safety issue, that you could move simultaneously, and when did you begin working on this particular service bulletin in terms of regulation, if you know, Mr. Cheney?

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

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

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

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

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

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

We have also got the issue with the scavenge pump connector that the NTSB brought to our attention during a tear down of an auto service scavenge pump, and we released a service bulletin on that, and the FAA has ADed that service bulletin that's currently being implemented.

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

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

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

CHAIRMAN HALL: And how many of those are ADs?

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

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

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

The current schedule of having that bulletin is --

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

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

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

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

CHAIRMAN HALL: What's the shortest AD that you all have ever put out?

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

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

WITNESS CHENEY: And we agree.

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

WITNESS CHENEY: January of next year.

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

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

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

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

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

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

MR. HULM: These measurements that we're taking are just stuff like the bonding and grounding straps on the tank, you know, the stuff that goes around the fuel tubes.

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

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

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

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

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

CHAIRMAN HALL: Do you treat it as a

recommendation, or do you do it?

MS. RODRIGUEZ: We do it.

CHAIRMAN HALL: Is that an Air Force requirement?

MS. RODRIGUEZ: Military.

CHAIRMAN HALL: It's a Military requirement?

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

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

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

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

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

CHAIRMAN HALL: Yes.

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

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

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

CHAIRMAN HALL: So Air Force I has been inspected?

MR. RODRIGUES: Yes, Mr. Chairman.

CHAIRMAN HALL: Thank you.

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

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

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

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

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

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

CHAIRMAN HALL: Don't count on it.

(Laughter)

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

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

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

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

Each operating certificate holder to implement a maintenance program; it's becoming clear, and has been clear to us throughout this investigation that tank maintenance hasn't been a high priority issue fleet-wide. It's something that we plan to take action on, but it's going to apply to more than just the 747, and more than just the Boeing fleet.

MR. HAUETER: Thank you, sir.

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

MR. HULM: Fifty-two.

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

MR. HULM: Correct.

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

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

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

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

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

Mr. Streeter?

MR. STREETER: Thank you, Mr. Chairman.

I'd like to start off for Mr. Thomas. Earlier, there was some discussion by the Board regarding the use of less volatile fuel, such as, JP-5. Is it the case right now that JP-5 is an approved fuel for any Boeing commercial airplanes?

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

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

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

Thank you.

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

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

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

WITNESS THOMAS: Yes.

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

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

MR. STREETER: Okay. Thank you, sir.

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

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

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

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

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

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

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

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

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

MR. STREETER: Answer the question, please.

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

Does that answer your question?

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

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

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

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

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

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

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

MR. STREETER: With a readout in the cockpit?

WITNESS THOMAS: Correct.

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

CHAIRMAN HALL: Thank you.

The Boeing commercial airplane group.

Mr. Rodrigues?

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

Do you feel that you know, understand how many various -- not how many -- but do you understand the various ignition sources that are available in the tank based on the development of the fault tree?

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

So, to state what ignition sources are in the tank, there are no ignition sources in the tank.

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

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

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

We have used that model. I think we

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

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

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

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

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

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

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

That looks to be very effective. We've

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

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

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

Does that answer your question?

MR. RODRIGUES: Yes, it does.

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

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

MR. RODRIGUES: Thank you.

That's all I have, Mr. Chairman.

CHAIRMAN HALL: Thank you very much.

The Airline Pilots Association - Captain?

CAPT. REKART: Thank you, Mr. Chairman.

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

WITNESS THOMAS: It's inside the tank.

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

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

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

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

Could you let him ask that question, please?

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

Now, were you paying attention?

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

Was that the one you were referring to?

CHAIRMAN HALL: And what was the answer?

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

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

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

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

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

DR. BIRKY: Mr. Cheney?

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

The FAA has already taken proactive action for the inspections of conduits in the fuel tanks for the wiring. In addition, the FAA initiated AD action for scavenge pumps before the service bulletin was issued.

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

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

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

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

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

CHAIRMAN HALL: Thank you.

Honeywell, Inc.?

(No response)

CHAIRMAN HALL: Crane Company Hydro Air.

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

CHAIRMAN HALL: Thank you.

The International Association of Machinists and the Aerospace Workers.

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

CHAIRMAN HALL: And Trans World Airlines, Inc.?

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

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

(No response)

CHAIRMAN HALL: Hearing none, does the Technical Panel then have additional questions?

MR. SWAIM: Sir, I've been passed up a couple of questions.

Have there been any scavenge pump ADs or service bulletins that were applicable to the TW 800 air flight? And I guess I ought to pass that question to Mr. Thomas or Mr. Hulm.

MR. HULM: The recent scavenge pump service bulletin that was released was applicable to the TWA airplane, but again, I think you have to understand the particular problem with the scavenge pump was at the connector itself and a part of the material in that connector. That connector is still located within that explosion-proof housing on the scavenge pump.

So, in relation to the accident, even though the scavenge pump was indicated that it was off, that really didn't have a bearing on that in that respect.

MR. SWAIM: So that's the only one applicable to the airplane - that airplane, the airworthiness?

MR. HULM: Yes, as far as I know.

MR. SWAIM: Okay. Mr. Hartonas, for the airworthiness directives, what were the compliance times given to the operators? How long can they go before they have to comply with those?

WITNESS HARTONAS: The compliance time for the scavenge pump, I believe, is 90 days.

MR. SWAIM: That's the newest one for the ground, the electrical connector?

WITNESS HARTONAS: Yes. The compliance time, or the common period for the proposed AD, the MPRM, is 90 days, and it provides for one year of compliance time.

MR. SWAIM: So, a year-and-a-quarter, essentially. Okay. Thank you.

I have no further questions at this time.

CHAIRMAN HALL: Do any of the Technical Panel have any questions?

MR. DICKINSON: I have one short question for Mr. Chris Hartonas.

You mentioned at the start of the conversation about the 200 microjewels as an industry standard, can you go over how the industry standard is established?

WITNESS HARTONAS: It is a long history about the establishing the energy level that would cause an ignition in the fuel tank. There is probably testing in volumes of the study. My knowledge simply has to do with the energy level. I'm not a fuel expert. I support the electrical systems in the equipment area.

Knowing that there is 200 millijewel energy level can cause an ignition in the tank is enough for me.

CHAIRMAN HALL: Any other questions from the Technical Panel?

(No response)

CHAIRMAN HALL: No. We have one last one.

MR. HAUETER: Mr. Taylor, previously this year there have been two electrical wiring fires outside the tank on 747. Does that give you concerns about the integrity of the jewel location system.

MR. TAYLOR: You're talking about electrical wiring fires of wiring not associated with the fuel quantity system?

MR. HAUETER: The fuel quantity system may run in those same bundles, yes, sir.

MR. TAYLOR: I don't really think I have a comment at this point.

MR. HULM: I would like to address that, since it's related to the wiring in the airplane and the wire fires that have been seen, the --

CHAIRMAN HALL: Well, I think that Mr. Taylor owes us either an answer, or he is not going to answer, one of the two. That's fine either way with the Chairman.

MR. TAYLOR: I think Boeing probably would have a much better answer.

CHAIRMAN HALL: Well, you make the product, and I think the question is, are you concerned about a fire on wire bundles that run into your product that you just make this long presentation on?

Is that the question?

MR. HAUETER: Yes, sir, it is.

MR. TAYLOR: I would say, the way the product is designed with the components we have built into it, that, no, we're not concerned. I don't think that wiring bundle fires are going to put 1,500 volts into a fuel quantity system.

CHAIRMAN HALL: Thank you.

MR. HULM: I kind of echo that, too. And in a little more detail, again, the components within the tank are rated up to 1,500 volts AC, and they test up to 1,500 volts AC. Any 115 volt source that comes from the airplane is not going to do anything inside the tank, and once you do get damage like, if you get 115 volts AC on that wiring, the indicator and the flight deck is going to fail, and you're going to notice it. The flight crew is going to notice it; the maintenance crew is going to notice it, and they're going to fix the system.

In addition to wiring that runs, the majority of the wiring runs from the flight engineer's panel down to the center tank itself is a high temperature teflon installation. The wire itself is rated for 1,000 volts AC continuous operation at that temperature, and the bundle for the FQIS system itself is protected with a varnished nylon sleeve to protect against abrasion. The nylon sleeve won't do you any good in a fire event, but it does prevent abrasion to the adjacent wires.

One thing we did notice from the accident investigation was that the wiring over the center tank, especially where there was the fire itself where a majority or all the wires that were in that particular channel where there were wire bundles routing, all that wiring was basically destroyed except for the FQIS wiring, which was pretty much intact.

So, that wire is some pretty tough stuff in consideration of wire fires and arcing and everything. But the overall consideration, if you get 115 volts on that, that wiring going to the tank - is that going to cause an ignition? - No, it won't. The components will withstand that; the wiring will withstand that.

DR. LOEB: Barring no other latent failures.

MR. HAUETER: I'd like to follow up on that. How do we know it won't? You say it won't. How do we know that?

MR. HULM: That's what we test in the lab. We took an entire center tank set up, probes, wiring and everything. We put that in a chamber that had fuel vapors in it, and it was kind of by accident, but that's the way the test was conducted.

Then we subjected that to up to 3,300 volts before we started seeing arcing and any of the insulated components.

DR. LOEB: And below that, you were unable to see any evidence of arcing under those conditions you were doing?

MR. HULM: Correct.

DR. LOEB: That doesn't mean that slight variations in that, you may not, I mean, we don't know what we don't know. We only know what we test for; is that correct?

MR. HULM: Correct.

MR. TAYLOR: If I could add to that. On that particular testing, you're not only just not seeing any arcing, but you're majoring in current flow and run it up to in excess of 3,000 volts and zero current flow, there is no arc, and it was very, very clear, when you really muscled this up and pushed it to the point where it was going arc, just from the indications, the arc was very evident and you would see the voltage drop, current go up.

DR. LOEB: Thank you.

CHAIRMAN HALL: Okay. Other questions?

DR. BIRKY: Mr. Chairman, may I follow that answer up with a question, sir?

CHAIRMAN HALL: Certainly, Dr. Birky, go ahead.

DR. BIRKY: Mr. Hulm, are you suggesting that in a fire outside the tank, that teflon will withstand that fire and maintain the insulation integrity of the wire?

MR. HULM: I can't make that guarantee, you know, in all cases. I'm just saying, that was one particular instance where there was a fire, and that teflon wiring did survive. I am sure there are other instances where the fire can be intense enough where it will destroy that wiring.

DR. BIRKY: Okay. Thank you.

CHAIRMAN HALL: No other questions from the Technical Panel?

Mr. Sweedler.

MR. SWEEDLER: Yes, Mr. Chairman.

I have one question for Mr. Thomas: We had quite a bit of discussion about what was found in this special service bulletin on the 52 airplanes that have already been inspected, but early in your testimony you describe a system where the operators of your airplanes can report problems back to you.

In those reports that come back to you, can you tell us about any particular problems that have been reported by the operators that cover center fuel tanks, temperatures in the tanks, possible ignition sources, anything of that nature that may have been reported by the operators of the 747s?

WITNESS THOMAS: Let me think about that. The short answer is, no. I know of no issues that would be considered a safety issue, other than the discussion we had already about the connectors outside the fuel tank themselves on the center wing pumps.

MR. SWEEDLER: Well, other than just the safety issue, are there any particular problems with the equipment in the tank?

WITNESS THOMAS: Not that I'm aware of.

MR. SWEEDLER: Okay. Thank you, sir.

CHAIRMAN HALL: Dr. Ellingstad.

MR. ELLINGSTAD: Both Mr. Cheney and Mr. Thomas used the term "explosion-proof," and I'd just like to get a clarification of what we are implying here.

Mr. Cheney, do I understand correctly that your use of this term was restricted to eliminating the threat of ignition of auto ignition from elevated temperatures on internal components in the tank?

WITNESS CHENEY: That's how it's intended in the advisory circular that I was discussing; that's correct.

MR. ELLINGSTAD: Mr. Thomas, you used this same term in connection with the performance of boost pumps, and seem to imply something a bit more general than that. What systems are explosion-proof from Boeing's point of view?

WITNESS THOMAS: We use the term, "explosion-proof" in two senses. One, if you have a component that is in a sealed compartment, if you will, and the compartment can tolerate an explosion with the surface temperatures reaching 390 degrees, or the appropriate temperature. That is considered explosion-proof.

We also look at the situation where we have a vented container, which is really the pump and motor housing that I described earlier, where not simply having a design with a temperature. The surface temperatures do not go over 390. That is part of the proof that it's explosion-proof.

The other part is that the venting of that chamber is also explosion-proof, in other words, the flame cannot propagate out of the chamber. So, there is a combination of those two tests that satisfy us that the pump is explosion-proof.

MR. ELLINGSTAD: Just to be clear, neither of you were using that language to describe a center wing tank that was subjected to an explosion?

WITNESS THOMAS: No.

MR. ELLINGSTAD: Mr. Thomas, with respect to your temperature limits - and again the Boeing standard of 50 degrees less than the auto ignition temperature - you did say that this applied to the inside of the tank?

WITNESS THOMAS: Correct.

MR. ELLINGSTAD: Under what conditions is that assessed, specifically, with respect to adjacent kinds of equipment that might assume different temperatures, air cycle machines, for example?

WITNESS THOMAS: Our design is such that we certify the design to ensure that we do not exceed 390 degrees anywhere inside the fuel tank. We look at ducting running down the leading edge, for instance, which we deliberately control to be normally below the 390 degrees. On extremely hot days, it may go up as high as 450. If there is a failure in the system where it could go higher than 450 in the leading edge, then we shut down the system.

We look at duct impingement, we have overheat detectors in the leading edge to protect the system; in other words, if I have a duct failure where I could be impinging hot air onto the center tank, in a local area, we will detect it and shut down the system supplying that hot air.

The other area in the airplane where you have obviously high temperatures, or in the fire zone of the engines themselves where they are quite a long way away from the fuel tanks.

MR. ELLINGSTAD: Okay, thank you.

Finally, Mr. Hulm, you have talked about the measurements that are taken and the protections with respect to electrical components. Are you exclusively concerned with arcing as an ignition source with respect to this standard in your tests?

MR. HULM: This particular standard is kind of basic to most aerospace components, and it has to deal with the insulating capability of the parts themselves in being able to last in the environment, the entire temperature pressure in life of the aircraft.

So, it's not strictly related to just arcing within fuel tanks. I think if you look at a lot of electrical components on aerospace equipment airplanes, you're going to find this requirement applied almost universally. So, it's not just specifically related to arcing, but that is the event you're looking for when you conduct these tests.

MR. ELLINGSTAD: Okay, thank you.

CHAIRMAN HALL: Dr. Loeb.

DR. LOEB: Mr. Hulm, I just want to revisit one more time this issue of your contention that there are no ignition sources within the tank. You have said that; is that correct?

MR. HULM: That's correct.

DR. LOEB: Does that not assume that there are no failure of any systems for that to be the case?

MR. HULM: That assumes under the conditions that we know about as far as different failures that could occur, that there are no ignition sources in the tank.

DR. LOEB: Are you suggesting that there is no combination of failures that could occur that could put an ignition source in that tank?

MR. HULM: No. I think we can imagine any combination of failures that can put an ignition source in the tank. What we have to look at in designing the equipment is, what is most likely, what is likely to occur? So, that's the way we do it.

DR. LOEB: No, I understand that, but I think it's important to clarify and not leave the impression that there is no possibility that there could be multiple failures that lead to ignition source.

MR. HULM: I concur, sir.

DR. LOEB: And Mr. Thomas, I wanted to follow-up just for a second on Dr. Ellingstad's questions regarding the auto ignition temperature in the systems that are there to protect against.

If you had a duct failure in the plenum above the tank and you were getting air temperatures above what you may normally expect out of the bleed (sic) air out of the engines, is there any system, any temperature-measuring device within the tank, or in that area that would protect against that kind of system where you were heating the ullage from the top with the air from the engines?

WITNESS THOMAS: There are several protection features there. The engine controls this in itself. It is regulating the air coming out of the engine up into the strut. We have cooling systems on board the engines, and they are in effect monitoring and regulating the temperature of the air coming out of the engine.

If that system sees a failure, it is capable of shutting down the valves that control the air coming out of the engine. If the failure occurs going down to the leading edge of the wing, we have overheat detection systems in the leading edge of the wing.

So, we have two mechanisms. We have an automatic control system that controls and modulates the air temperature going from the engines down the leading edge, and then we have overheat detectors in the leading edge.

Mr. Cheney referred to the wheel wells. We have fire detectors or overheat detectors in the wheel wells, where there is overheat in the wheel well that could be potential problem to the rear spar, and then the crew gets a warning, and they're instructed to lower the landing gear, which in effect sweeps any combustibles out of the landing gear bay itself and puts the fire out.

DR. LOEB: Is the air in the ducts above the tank with no failures in the system, is it other than, say, a failure in the duct, is it hot enough to heat the tank to auto ignition?

WITNESS THOMAS: There are no ducts above the tank. They're on the leading edge on the forward of the tank.

DR. LOEB: Right; yes. But they can get to that area of the tank. Now, is that air hot --

WITNESS THOMAS: No. That air is normally running at 350 out there, but not enough. By the time you cool that air in the mixing process from the leak to the front spar, plus the temperature that it will be of heat that will be transmitted away from in the spar itself, we do not see there is any way that we can get to 390 degrees inside the tank.

DR. LOEB: Okay. Thanks.

CHAIRMAN HALL: I just have a few questions so we can finish up on time, and this being the fuel design, tank design philosophy and certification panel, I understand that the basic philosophy is to engineer out the ignition sources. Its been done in the past, and I appreciate what's been mentioned by FAA and Boeing to look at the issue that's been raised about the explosive vapors.

But just to stay on the engineering, not the ignition sources for a minute: That, I guess, assumes that there are some ignition sources that could possible get in the tank, and you have identified those, or not. I guess we couldn't put a number on that, either Mr. Thomas or Mr. Hulm.

I'm referring now, I guess, to what the industry response to the FAA was in the request for comment, Title, Fuel Tank Ignition Prevention Measures. I don't' know if that's an exhibit to this?

MR. SWAIM: I believe, sir, we will be referring to that in the flammability reduction.

CHAIRMAN HALL: All right. So, therefore, the industry plans to voluntarily undertake either a sampling of high time aircraft or major fuel tank inspection programs to (1) verify the integrity of wiring and grounding straps; (2) the conditions of fuel pumps, fuel lines and fittings; and (3) the electrical bondings on all equipment.

So, would failures or malfunctions of those be possible ignition sources in the tank, or why is that inspection program being undertaken?

MR. HULM: That is the purpose behind the inspection program is to look to see if there has been any degradation in the bonds or grounds that have occurred.

CHAIRMAN HALL: And you've got to open the tank to do that?

MR. HULM: Correct.

CHAIRMAN HALL: And you say you're concerned about how often you open the tank. Do you have guidelines on how often you open the tank?

Boeing?

WITNESS CHENEY: I think that was a comment I made. Currently, there is no requirement to --

CHAIRMAN HALL: Well, let me ask Boeing: Do you have a concern about opening the tank?

MR. HULM: I think we definitely do.

CHAIRMAN HALL: Do you have a time, do you have how often it should be opened and inspected?

MR. HULM: We don't provide any

recommendation along that respect.

CHAIRMAN HALL: Well, what I'm trying to understand, what I'm trying to grasp is, we engineer, under the concept we've had in the past, we engineer out the ignition sources. We have identified possible areas of electrical components leading into the tank that might be possible ignition sources, and I think I understand that you try, even if there are failure modes of those, to be sure there is not enough energy to ignite the tank.

But, then, that's never inspected, except when? How often is that inspected and looked at? Because it would seem to me, unless you inspected those routinely, then the basic premise of which your philosophy is based on needs a little improvement.

MR. HULM: The way the systems are designed, is that we don't have any regular maintenance. We at Boeing don't have any regular maintenance that requires tank entry. It's all on condition if there is a failure of a component within the tank, then we do specify how to correct it and repair it.

WITNESS THOMAS: In addition to that, because of the structural inspections I referred to earlier where we needed to go and look at the tanks to see how well the structure is doing with time, we do what we call zonal inspections are called out where, if you're in a tank area looking at the structure, you also look at the condition of the systems in that general area.

There are other checks that we do, things like the check valves that I referred to on the boost pumps, some of the ellens (sic) will remove those check valves, run through a vent and restore them into the airplane, and we do functional tests on the airplane to look for those kinds of failures.

So, it's a combination of periodic tank visits really as a force by the structural inspection requirement, but also allows us a chance to look at the fuel system. We don't go into the fuel system -- go into the tanks specifically to look at a fuel system on a regular -- this inspection program --

CHAIRMAN HALL: Could I ask Ms. Rodrigues, does the Air Force have any different requirements in what was described for your center fuel tank inspections?

MS. RODRIGUEZ: We have depot maintenance inspection. Again, it depends really on the program on the airplane. Most are made in, like --

CHAIRMAN HALL: Well, give us the 747.

MS. RODRIGUEZ: -- five years. Five years, and at that time, we do an extensive functional check of the fuel system; otherwise, it is only on either you have a leak or a component fails, and we don't have a limitation of how many times you can enter the tank either; as much as is needed to repair.

CHAIRMAN HALL: Well, I would hope that the FAA would look into that matter because we need to clarify for the traveling public what inspection we're doing and what the reasonable time frame is we're going to do it in, and you say, it's already been accomplished on Air Force I. I'm sure most citizens would want it accomplished on the 747 thereon, as well.

Did any of the members of the Panel have any other comments that they would like to make or contribute? I appreciate all of you all. I have read your backgrounds and biographies. All of you all have impressive credentials in your field.

Mr. Cheney and Mr. Thomas, I appreciate your service to the Government, and if any of you all feel that there is anything that we have missed or any personal contribution you would like to make or comment, please take the time to do so.

Mr. Taylor?

MR. TAYLOR: No, thank you. No comments.

CHAIRMAN HALL: Mr. R. Thomas?

MR. R. THOMAS: Not at this time, Mr.

Chairman.

CHAIRMAN HALL: Mr. Cheney?

WITNESS CHENEY: No, Mr. Chairman.

CHAIRMAN HALL: Mr. Thomas?

WITNESS THOMAS: I would just like to reiterate what I said in terms of this activity we're undertaking today where we're addressing fuel flammability, is a major philosophical relook at how we do it. It's very important. The Boeing Company is very committed to pursue this. The FAA has proposed the Eric process as a way of doing "a fast track" activity, to look at all these suggestions.

We totally support that activity, and really want to press forward.

CHAIRMAN HALL: Well, Boeing is one of the largest companies in our country, and everyone is familiar with that name like they are "Coca-Cola." Well, I'd better not say any other names.

I appreciate the questions from the Boeing table because all I wanted to get out was what you were doing, since TWA, and I knew you were doing a number of things, but I think it's important in this public hearing on this accident that the American people know what the manufacturer of the plane is doing.

None of are saying we know what caused the accident. We don't have the ignition source for this accident, but what are we doing as a Government, as an industry, as an airline, to be sure that until we know, that we're doing everything that you or I would want done.

Mr. Hulm?

MR. HULM: I guess I'd also like to clarify some of my comments to make sure. I agree with you, the fact that we don't know what caused the explosion in the center tank at TWA-800, and we're not closed to anything at this point in time. We are keeping an open mind, and there is nothing that we have ruled out as any sort of possibility, and so if something does come up and the work with the NTSB is done, and working with the FAA, I think the cooperation there has been pretty good, and there has been a lot of good work put in; but there is still one heck-of-a-lot-of-work to do.

So, we're not closed off from that.

CHAIRMAN HALL: Thank you very much.

MR. HULM: Thank you, sir.

CHAIRMAN HALL: Ms. Rodriguez?

MS. RODRIGUEZ: No comment.

CHAIRMAN HALL: And I can't see that far, so you will have to help me with the name again, sir. I apologize. I don't have it in front of me.

WITNESS HINDERBERGER: Ron Hinderberger.

CHAIRMAN HALL: Yes, Mr. Hinderberger.

WITNESS HINDERBERGER: Mr. Chairman, I guess I would just like to add that as an industry, there is a genuine concern right from the beginning of this accident, and our participation at Douglas Aircraft at the time of the accident, since becoming part of the Boeing Company, of course; but right from the beginning of the accident, the industry as a whole, speaking on behalf of Douglas Aircraft, became very concerned about this accident and have been very active in various committees to try to uncover as many possibilities as we can to get to the root case, and what can we eventually do to make air travel even safer than it is today.

CHAIRMAN HALL: Well, you have been an excellent Panel, and I appreciate very much your presentation.

You are excused, and we will stand in recess until 2 o'clock, at which time we will return for the Flammability Panel.

(Whereupon, at 12:53 p.m., the hearing in the above-captioned matter was adjourned for luncheon recess, to reconvene at 2:00 p.m., this same day.)

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 THIBAULT, 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 consist of presentations by Dr. Birky, Dr. Bower and various Panel members.

Questioners will also be questioned by Mr. Dennis Crider.

Dr. Daniel Bower has been with the Safety Board for two years as an Aerospace Engineer. He served as an Performance Group Chairman on several major accidents, including the 1996 Value Jet accident in Florida.

Prior experience includes Research Engineering at the Calspan University at Buffalo Research Center where he performed experimental research in hypersonic aerodynamics and heat transfer.

He also worked as an aerospace engineer at the Air Force Wright Aeronautical Laboratories. He has a B. S. in Aerospace Engineering from State University of New York in Buffalo, and his Ph.D. is in Aerospace Engineering, specializing in compressible fluid flow and boundary layer stability.

Dr. Merritt Birky has been with the Board for 14 years. He is a National Resource Specialist in the Office of Research and Engineering. He has participated in the investigation of some of the nation's major aviation accidents, including the downing of PanAm Flight 103, the Space Shuttle

Challenger, the U. S. Air Force Titan, and the Value Jet investigation.

He has participated in the investigation of major railroad, pipeline and marine accidents also, including the Exxon Valdez in Alaska.

Prior to joining the Safety Board, he worked for more than 20 years at the National Bureau of Standards, then served as Director of Research at the Foundation for Fire Safety.

CHAIRMAN HALL: Mr. Dickinson, do you know if Dr. Birky's biography is on the Internet?

MR. DICKINSON: Yes, sir. All the biographies have been entered in on the Internet.

CHAIRMAN HALL: The Chairman was disappointed when he noticed that Dr. Birky's biography was not on the Internet this morning. I want to be sure it's on the Internet before we proceed.

Dr. Ellingstad, has that been done?

MR. ELLINGSTAD: Yes, sir.

CHAIRMAN HALL: Very well.

Well, we may proceed then.

MR. DICKINSON: Getting back to Dr. Birky, he has a Bachelor's Degree from Goshen College, and a Doctorate from the University of Virginia, and he has done some work at NIH Graduate School in Toxicology.

Dr. Joseph Shepherd is an Associate Professor of Aerospace.

CHAIRMAN HALL: If your names are there, please hold your hand up as you are introduced. I would appreciate it.

(Dr. Shepherd raised his hand)

MR. DICKINSON: Thank you, Dr. Shepherd.

California Institute of Technology; he heads the Explosion Dynamics Laboratory at Cal Tech in Pasadena; directs experimental and computational studies on combustion, explosion and shock waves; specializes in studies related to safety and explosion hazards in transportation systems; has 17 years experience in experiments, analysis and computation of explosion phenomena.

Dr. Shepherd has been a Consultant, an investigator on numerous projects for the DOE, U. S. Nuclear Regulatory Commission, NASA and various national laboratories. He has a B. S. in Physics from the University of South Florida, and a Ph.D. in Applied Science, California Institute of Technology.

Next, we have Dr. Sagebiel.

(Dr. John Sagebiel raised his hand)

MR. DICKINSON: Thank you.

Assistant Research Professor, Energy and

Environmental Engineering Center, Desert Research Institute, University of Nevada. He has had five years with DRI, and it's centered on sampling and measuring of hydrocarbon species in ambient air and source samples.

He has worked on the development of numerous analytical methods, and worked on performance evaluations of air sampling systems.

He has a B. S. in Environmental Toxicology.

Dr. Melvin Baer.

(Dr. Melvin Baer raised his hand)

MR. DICKINSON: Thank you. Is a Senior Scientist with Sandia National Laboratories; he was 21 years with Sandia at the Engineering Sandia National Laboratories in Alberquerque, New Mexico; promoted to Distinguished Member of the Technical Staff in 1989; has conducted extensive scientific research in the field of Energetic Materials and Explosives; served as a participant on numerous hazard evaluation programs for the Department of Energy and the Department of Defense.

He has a B. S., M. S., and Ph.D. in Mechanical Engineering from the Colorado State University.

Next, we have Dr. Paul Thibault.

(Dr. Paul Thibault raised his hand)

MR. DICKINSON: From Combustion Dynamics Limited, he founded that organization, which provides scientific software and analysis services in the areas of explosions, shock waves, supersonic combustion and propulsion, CDL; has developed strong capabilities in computational fluid dynamics, and computational solid mechanics.

It operates a laboratory facility for combustion experiments and a large-scale heated detonation tube facility.

He previously worked at the Pat Bay Ocean Science Institute at the Defense Research establishment in Suffield, and worked on detonations, flames and gaseous explosions at McGill University, from which he got his Bachelor Degree in Mechanical Engineering in 1972, and his Ph.D. in 1978.

Following him, we have Dr. Kees Van Win Gerden.

(Dr. Kees Van Win Gerden raised his hand)

MR. DICKINSON: Thank you, sir.

He's the Manager of the Department of Process and Safety in Christian Michaelson Research, otherwise know as Sam R. He is employed at Sam R, he has been employed since 1991. Dr. Van Win Gerden is responsible for research into gas and dust explosions. He has directed a number of large research programs, such as the gas safety program sponsored by several gas and oil companies and Government bodies, and resulting in three new versions of the facts code. It's a three-dimensional exposure simulator.

Dr. Van Win Gerden is author and co-author of more than 50 articles on gas and dust explosions. His education includes a B. S., and M. S. and a Ph.D. in Applied Physics from the University of Bergen in Norway.

And last, but not least, we have Mr. Jim Woodrow, who is a Laboratory Manager at the University Center for Environmental Sciences and Engineering at the University of Nevada at Reno. He has worked for Dow Chemical Company, Shell Development Company, and has been a teaching assistant at the University of California; is currently the Laboratory Manager for the University Center for Environmental Sciences and Engineering, University of Nevada at Reno.

And his education includes a B. A. and an M. S. in Chemistry from San Jose State University.

With that, I will turn the microphone over to Dr. Merritt Birky.

Are you going to be first?

Presentation By

DR. MERRITT BIRKY

MR. BIRKY: Good afternoon, Mr. Chairman, Members of the Board of Inquiry, Ladies and Gentlemen.

This is a Flammability Panel. What I would like to do in terms of sequence to give you a bit of a road map, is that I will give a short presentation, followed by Dr. Bower, then followed by Dr. Shepherd, and then very short with Dr. Sagebiel and Mr. Woodrow, and then will go back to Dr. Shepherd, and then go into the modeling with Dr. Thibault and Dr. Mel Baer.

I would like to start with a very short tutorial on flammability, and I think we got into a lot of that this morning. Some of it will be a bit redundant, but hopefully, some of it will stick as a result of that. So, what we're going to do, the Flammability Panel will go into laboratory explosion results, flight test data, vapor chemistry, quarter scale and modeling.

For the tutorial, I have a few cartoons, I think, that will demonstrate the relationship between ignition sources and flammability. And that was a big issue of discussion this morning.

For a fire or explosion to occur, we must have three elements, that is, we must have oxygen, fuel and an ignition source. If you want to interrupt that process, that is, prevent an explosion or fire, one has to remove one of those three elements: Ignition source, which is the philosophy which has been used on aircraft, but the other way to do that is to eliminate the fuel.

It's very difficult to eliminate the oxygen unless you do some type of inner process.

Solids and liquids do not burn. They must first be converted to vapor, converted into the vapor phase. If you're talking about Jet A in an aircraft tank, then you generally must have some heat to do that.

Jet A is a very complex fuel, and made up of many different compounds. The vapors that we're talking about for an explosion in this case were generated when the bottom of the tank containing about 50 gallons of fuel, and it was heated up as a result of the air-conditioning packs used to condition the cabin of the aircraft.

These vapors are very much like that that comes off of a pot of water on the stove when it's heated, although in this case, the vapors are flammable, that is, they will burn, and the water vapors are not flammable.

This graph is used to illustrate the vapors in the air in a tank; the red line at the bottom is a liquid fuel. In this case, we're talking about Jet-A. The red circles are the hydrocarbon molecules, and the blue represent the oxygen in the tank.

This slide represents sort of a cold situation in which you have very few molecules of the hydrocarbon in the vapor phase, so you're not likely to have a fire or an explosion in that case. If we put heat under the tank, then we increase the number of fuel molecules for that combustion process to occur.

Now, I tried to use a little bit different size circles for the fuel hydrocarbon molecules to represent different compounds, if you will, since it's a very complex mixture.

As you heat up the fuel, the number of those fuel molecules, of course, increase into the ullage space, or the vapor space that we have above the liquid fuel, and if you hear the word "ullage" in my presentation and others, we're referring to the space above the liquid inside the tank, the air space, basically.

Now, if I take a cup of Jet-A or any combustible liquid and slowly heat it up, and have an ignition source at the top of that, I will come to a point which the vapors will support combustion, and that point in which that happens is called the flash point that we've talked about before.

There is a standard ASTM method that's used for that measurement, and fuels are frequently classified according to that test method, and there is a thermometer indicated in that cartoon there, right there (indicating).

Now, I can do a series of experiments with that particular apparatus, and this is a plot that shows the temperature on the horizontal axis and the altitude on the vertical axis. I direct your attention over to the right-hand side of that screen, and Jet-A, for example, has a flash point roughly, usually above 100 degrees Fahrenheit, as we heard this morning, and that at sea level, which is zero altitude, is down here.

If I do that same measurement at altitudes, say, at the top of Pike's Peak at about 14,000 feet, I will get a flash point that will be at a lower temperature, a little bit than that at sea level. If I continued to increase the temperature in that apparatus that had previously had shown, I will reach a level at which the fire no longer continues to burn, and that is the temperature here indicated at that point, about 190 degrees, something like that.

Those two lines then, if I do that temperature at different altitudes, those two lines represent the lower flammability limit, as indicated, and the upper flammability limit.

The Jet-A that we had from a net tank on TWA-800 had a flash point of about 113 degrees Fahrenheit. For comparison purposes, I put on there the flash points of gasoline, since most people are more familiar with gasoline in their automobiles, and by the way, this slide basically comes from the reference literature and represents typical fuels.

Now, as you see in that graph, the flash point, the lower flammability limit of gasoline at sea level is approximately minus 40 degrees Fahrenheit, and for those in the audience that have diesel cars, this graph explains why diesel fuel cars are harder to start in the wintertime than those in gasoline cars, for Diesel has a flash point very similar to Jet-A. It's a kerosene, as Jet-A is, and if you remember what I said earlier, for fuel to burn, it must be in the vapor state.

In the wintertime, when the fuels are very cold, the diesel fuel has very few molecules in the vapor phase, so it makes it harder starting an automobile in the wintertime on diesel fuel.

Now, if I put this Jet-A inside a closed container and heat it up, and then put a spark inside, the container, will, of course, explode or burst, and that's the result of the generation of pressure from the heat and from the gabushen (sic) process. This explosion can be extremely powerful.

Now, having talked about the fuel side of the equation of the triangle, let me go on to the ignition side, if I might.

The amount of energy that is required to ignite hydrocarbon vapors is strongly dependent on the temperature of the liquid. The scientific literature states that the minimum energy for hydrocarbon vapor ignition is roughly one-quarter of a millijewel, and we heard a lot of discussion about this this morning.

The question was raised, how much is a quarter-of-a-millijewel? Well, we can illustrate this -- sorry -- before I go on and do that illustration, let me point out two things: There are two temperatures I talked about this morning that I just put into this presentation, the flash point and the auto ignition point, and they are quite different. As you can see, the flash point of Jet-A is about 100, and the auto ignition temperature of Jet-A is about 450 degrees.

Let's now go back to the ignition issue. I chose to represent the quarter-of-a-millijewel, as I stated this morning, by holding a dime about a half-an-inch above the table top, and that dime held there has roughly the potential energy of a quarter-of-a-millijewel, and if you drop that dime, that energy, potential energy, will be converted to kinetic energy and will strike that table with that appropriate energy.

As you can see, this is a very small amount of energy, so small, in fact, that is this is the energy that ignited the tank in Flight 800, there would be no signature witness mark to see in the recovered hardware. Is this the amount of energy is actually took to do that in this particular accident?

Well, we don't know that, but if the energy is higher, that is, if the fuel is considerably colder, it may take up to 10-to-100 jewels. We are going to hear more about that; and the question then is, how much is that?

Well, if I am talking about 10-to-100 jewels, then I want to illustrate it with my dime. I would have to put it about 5-to-6 miles in the air to represent that type of energy. Obviously, we won't get it when it hits, but that's basically if you want to run a tube and valuate that distance, you could probably do it.

When we first realized an explosion at center wing tank on this aircraft, it was a primary or initiating vent that resulted in loss of the aircraft. The first obvious question was: Why were the vapors above the lower flange limit; and second, what was the ignition source for the vapors?

The work that we're going to be reviewing has the ultimate goal, the identification of the ignition source. Part of this inquiry is knowing how much energy is required to ignite the vapors, and within the tank there are two general classifications in that tank that we could put in that is a higher energy system, that is, the fuel pumps we talked about, and a lower energy system, the gauging system.

If a large amount of energy is required, then we're talking about other than the gauging system.

I would like to show a picture on the visualizer right not that illustrates the gauging system in the tank. There are tubes. Everyone, I think, is now pretty familiar with the gauging system in the tank, and the pumps, of course, in the back spar.

Of course, there are other possible ignition sources that we won't address here, but we will addressing ignition sources in the next Panel, and that concludes my sort of a tutorial on flammability, and I'd like to go on to reviewing the flammability program.

As a result of these questions regarding this accident, a number of programs were initiated on the flammability of Jet-A fuel. The objectives and progress of these programs are going to be reviewed briefly here in terms of principal findings as they relate to flammability conditions in the center wing tank.

The objectives are shown on this slide, that is, to try to determine the source of ignition and as a backup position, fall back position, determine the location within the tank, if possible, the ignition source; and determine the fire and explosion properties of Jet-A, and certainly determine the ignition energy.

To carry out this program, the Safety Board enlisted a number of experts from around the world in Fuel Chemistry, Fuel Flammability, Analytical Chemistry, and Computer Modeling of Combustion Explosions.

The first program we initiated to measure the flammability Jet-A in the laboratory explosion chamber was with the California Institute of Technology under the direction of Professor Joe Shepherd. This program, initial program, has grown well beyond the original laboratory measurements to explore testing programs up to a quarter scale modeling of the center wing tank.

The objective of this program, of course, laboratory programs measure the rate of pressurized and peak pressures and minimum ignition energy using Jet-A fuel.

Almost simultaneously with this initial testing program, the Safety Board contracted with the University of Nevada at Reno to determine the vapor pressure and vapor chemistry of Jet-A under different conditions under the direction of Mr. Jim Woodrow.

These two programs were set up and operating before a flight test program was designed and carried out. The objective of the flight testing was to determine the conditions inside the center wing tank that led to the explosion. As we will hear, the primary driving force for the flammability, of course, is the air-conditioning packs underneath the tank.

When this flight test was designed, it was decided to collect vapor samples at different times during the flight test to determine the vapor chemistry. These flight tests were probably the most fundamentally important program that the Safety Board carried out in helping you to find not only the conditions inside the tank for guiding explosion testing, but also to help us develop ways to reduce or eliminate the risk of an explosion inside this tank.

The flight testing was done with the assistance of the Boeing Company and Dr. Dan Bower will review the flight test effort.

The decision to do vapor sampling inside the tank during the flight led to the contract with the Desert Research Institute at the University of Nevada under the direction of Dr. John Sagebiel. Dr. Sagebiel provided the expertise for this sampling and for the analysis of that those samples.

Early in explosion testing at Cal Tech, it was determined by the Safety Board that laboratory measurements, although fundamentally important understanding of what happens when Jet-A vapors are ignited, such measurements by themselves could not be used to determine how the center tank would react to an explosive mixture on ignition.

As a result, large-scale or full-scale testing was considered important. Because of the cost and time of procuring multiple 747 wing tanks was prohibitive, a quarter-scale testing of model center wing tank was chosen to study the effects of partitions in the tank, the effects of jetting between compartments, and the effects of changing ignition location within the tank.

Again, for this program, the Safety Board turned to Cal Tech, Dr. Shepherd, and then also to Applied Research Associates in Denver for this work. Another fundamental issue drove the decision to do quarter-scale testing.

The signature from an ignition source had not, and has not, been identified in the investigation of the TWA accident, and the question arose as to whether or not an ignition at different locations inside the center tank would result in different outcomes in terms of the damage to the tank, and whether or not an analysis of such damage would help the Safety Board to identify the location of the ignition within the center wing tank.

Simultaneously with the quarter-scale program, it was decided to have a computer modeling program interact with the experimental testing program. The purpose of the modeling program was to facilitate the testing program, and thus, reduce the amount of experimental testing and to provide insights into the effects of ignition location on explosion dynamics.

Consequently, the Safety Board contracted with two separate facilities in order to use two different computer modeling approaches. Sandia National Laboratory in Albuquerque under the direction of Dr. Mel Baer, was one of the programs chosen.

The second program selected was a joint program with Christian Mickelson Institute in Norway under the direction of Dr. Kees Van Win Gerden, and with Combustion Dynamics in Canada under the direction of Dr. Paul Thibault.

This is a very brief review of the rationale for the experimental programs that were undertaken to assist the National Transportation Safety Board in investigation of this accident.

As you can see, we enlisted the assistance of top experts worldwide to help us find the cause of this accident. These programs had already provided important information about Jet-A, and the conditions inside the center wing tank that will lead to improve aviation safety, and we believe continuation of these programs will provide more information for improved aviation safety.

That concludes my remarks, and I would like at this point, to turn the program over to Dr. Dan Bower, who will review the test flight program and provide some of the flight tests results to guide us further.

Dr. Bower.

Presentation By

DR. DAN BOWER

DR. BOWER: Thank you, Dr. Birky. Good afternoon, Mr. Chairman.

As described in Dr. Birky's presentation, flammability of a fuel vapor air mixture are dependent upon the temperature, and pressure and the mixture. Early in the accident investigation, it was recognized that fuel air mixture existed in the center wing tank of TWA 800 at the time of the accident.

We were able to determine from the flight data recorder, altitude data, the pressure that existed in the center wing tank at or near the time of the explosion; however, based on the information known at the time, no accurate assessment of the temperatures, and hence, the level of flammability which may have existed in the center wing tank is possible, and little information existed about the typical temperatures inside a center wing tank during normal flight operations.

In order to accomplish our objectives in testing computer modeling, the conditions that existed in the center wing tank needed to be determined. In an effort to determine the conditions that existed inside the center wing tank, the Safety Board designed a flight test program, leased a 747-100 Series Aircraft, and performed an intensive series of flight tests.

The flight test program was designed to not only determine the conditions that existed in the center wing tank before the initial explosion, but also to further the understanding of the heating process to the center wing tank, understanding this heating process may help to develop means of reducing the temperature and enhance the flammability of the tank.

I will give a brief overview of the flight test program and summarize some of the results obtained during the flight test. An extremely large volume of data was collected in these flight tests, and the analysis of this data is still on-going.

The flight test program took place between July 11th and 20th this past summer. Flight tests were flown out of JFK Airport and coincided with the one-year anniversary of the accident flight. Participants in the flight test program were the FAA, Boeing

Commercial Airplane Company, Trans World Airlines, Air Line Pilots Association, and Evergreen Airlines, the owner of the test aircraft.

All of the parties participated in the review of the flight test plan and were briefed on preliminary results following each flight. As we stated, the main objective of the flight test series were to obtain air temperature measurements and pressure measurements inside the center wing tank, also, in the wing tanks, the vents from the center wing tank, and in the wing tip surge tanks.

We also wanted to measure surface temperatures on the external surface of the center wing tank above the environmental control system units or the air-conditioning packs, and we also wanted to measure surface temperature measurements of the ECS pack components.

We additionally want to measure.

CHAIRMAN HALL: What is ECS?

DR. BOWER: Environmental Control System, another name for the air-conditioning packs.

Additional objectives of the flight test were to measure the vibration of the center wing tank bottom. We wanted to determine if sufficient vibration existed to loft the liquid fuel. Lofting refers to the shaking or the jarring of the liquid fuel enough to create a mist or a small drop of the fuel.

DR. LOEB: Could you explain, Dan, the relevance of that, please, the lofting the dynamics; and if you can't, maybe Merritt should right now.

DR. BOWER: Perhaps Merritt can.

MR. BIRKY: Yes. One of the issues related to the flammability of the tank is whether or not vibrations and motion of the tank will cause small droplets to come off the surface and be airborne, if you will, into the tank and cause the tank to be an explosive range or above the lower flammability limit more than you would have just with the temperature driving that.

If you go back and remember the curve I showed you with the lines going off to your left with altitude, those vibrations, the thinking was in some of the literature, the older scientific literature, that this would cause the tank to be in the flammability range much more frequently than is normal in a case, and so that was the reason for doing these vibration tests on the test flight.

DR. BOWER: Thank you, Dr. Birky.

The Safety Board leased an aircraft from Evergreen Airlines for the test. The leased airplane was a 747-121 series aircraft, which was a similar model to the accident aircraft, which was a Series-131 model, and the test aircraft was Boeing line number 106.

The Boeing Commercial Airplane Company provided the instrumentation, installed the instrumentation on the aircraft and the supervision of the Safety Board, and also provided the flight crew for the flight test series.

I would like to acknowledge the fine work that the Boeing flight test group did in that group, and we thank them. I also would like to acknowledge the work of Mr. Robert Benzing, Mr. Bob Swaim and Dr. Burke from the Safety Board in helping to develop the flight test program and carry it out.

On the test aircraft we installed over 153 temperature sensors, or known as thermo couples. Additional sensors were measured to measure pressure, tank bottom vibration and custom equipment was designed and installed to obtain vapor sample from the center wing tank during the flight test.

Now, before I proceed with my presentation, I just want to mention that some of the nomenclature I'm going to use in my presentation just so we're familiar with it in terms of the center wing tank. This views is a top view of the center wing tank. We have the Drive A in front. Bay 1 is referred to as the bay between span wise beams 2 and 3. I will refer to bay 2 as the bay between span wise beam 2 in the mid spar.

The two bays between span wise beam 1 and the mid spar referred to as the left and right mid bays, and the bays between span wise beam 1 in the rear spar is the F bays, and this is obviously mislabeled. I'm sorry.

The ullage I am referring to is the space in the fuel tank above the liquid fuel, which is occupied by fuel vapor.

And now I'd like to show a quick video which is going to detail some of our instrumentation locations inside the center wing tank. Shown here in this video, the white spheres represent the location of our air temperature measurements inside the center wing tank. See, we have several located in all of the bays, and these are designed to measure the air temperature in the ullage for the temperature of the fuel air vapor.

As we move our view, we see the front two bays. We have three trees of thermo couples, and then the F bay center, we have three trees of thermo couples measuring air temperature near the bottom of the tank, the middle of the tank, and near the top surface of the tank.

And as we move around we can get a good view and idea of the relative temperature locations, measurement locations. As we see from the pull out view, we do not make any measurement in the Drive A; only in the bays which contain the fuel vapor.

And I might add that what we have in this video was only a portion of the temperature measurements that were made on this tank and in the airplane. We now spin the tank to examine some of the instrumentation on the bottom surface. We have noted in green some of the measurements were made on the air-conditioning pack components, and the white disks on the bottom of the tank represents surface thermo couples to measure the temperature of the external bottom surface of the tank.

Now, we did have additional measurement locations in other parts of the aircraft also. We switch back to a top view. We see two of the thermo couples to the right; they are located in tank 3, and we will have a better view of that in a second.

Now this view shows the fuel tanks, the schematic of the fuel tanks in both the wings. The little square at the end of the wing tips represent the search tanks in the wing tips, and we have shown one of the vent stringers, which is a vent leading from the center wing tank out to the search tank, and we have measurements inside that search tank at the wing tip.

(Pause)

DR. BOWER: And as we spin the tank back, we have another view of the thermo couples represented by the green squares on some of the air-conditioning pack components, and we see we have a good relative location of some of the surface thermo couples on those pack components, and as you notice on the one side, there are more than the other, and that side represents the side of the airplane which housed two of the air-conditioning units, which from the top view is the left side, as you can see here.

The entire flight test program consisted of nine flights. For each of the flights, balanced weight was added so that the gross airplane weight was the same as TWA 800. The fuel load and the central for TWA 800 was duplicated in each flight as closely as practical.

Different combinations of the air-conditioning packs were used to provide different heat loads to the center wing tank in each flight, and one flight was strictly dedicated to replicating the preflight operations and flight conditions of TWA 800, and to prevent the center wing tank explosion from occurring on the flight test, prior to the beginning of the flight test series, the entire center wing tank was fully inspected to ensure that no ignition sources were introduced or existed in the center wing tank.

Now, for these flights, 50 gallons of liquid Jet-A fuel was placed in the center wing tank. The Jet-A fuel used in these flights was loaded onto a 747 at Athens, Greece, and flown on a regular service flight from Athens to JFK Airport. The Jet-A fuel was offloaded from the regular service airplane, transported, and 50 gallons was loaded into the center wing tank of the test aircraft prior to the first test flight. This fuel remained in the center wing tank for the first four test flights.

As described previously, one of the major objectives was to obtain vapor samples at the different temperatures and pressures which occur in the center wing tank during an ascent and near the TWA 800 accident altitude. On three of these flights, which had the liquid Jet-A in the center wing tank, vapor samples were obtained on the ground during taxiing, as the airplane reached 10,000 feet, and as the airplane passed through 14,000 feet.

Dr. Sagebiel will discuss in more detail the analysis of the vapor samples obtained in the flight test. Liquid samples of the Jet-A fuel were drawn from the center wing tank several times in the flight test program, including one sample before the test program began.

Mr. Woodrow will address the analysis of these liquid samples.

I am now going to address the results from one of the flights, which is referred to as a TWA 800 emulation flight. The conditions, preflight operations, taxi and take-off of TWA 800 were replicated as closely as possible in the emulation flight. The flight was performed prior to the emulation flight, which flew up to 35,000 feet and landed at the same time as the accident airplane previous flight, TWA 881.

Upon completion of taxiing from that flight, the environmental control system units, or the air-conditioning packs 1 and 3 were placed in operation. These units remained in operation for the entire ground portion of the emulation flight, or for approximately 3-1/2 hours.

Efforts were made to perform all preflight operations at the same time of day as TWA 800, including loading the fuel, pushback and start of taxiing. The lift off of the test flight occurred within one minute of the time of lift off of TWA 800.

Shown in this block is a comparison of flight test altitude time history as compared to the data recorded on the TWA Flight 800 flight data recorder, and altitude as a function of time, and we see that the current lift off, the flight crew matched the central file exceptionally well, including the slight level off of 6,000, level off of a slight descent, 13,000 back to 12,800, and up to the event altitude.

The test flight crew matched the central file while they reached the explosion altitude of TWA 800 within ten seconds.

I will now show animation that will take some of the data collected in this test and the same format as previously done. Now, this animation will begin at the start of the on ground portion of the test, that is, when the pack 103 were turned on. The time is accelerated on the video quite a bit, and on the right-hand side of the animation is the temperature scale, represents the temperatures and the measurement locations only.

The color of the tank structure does not represent the temperature of the structure, and as we run the pack, we see that the left side starts becoming warmer before any other portion of the tank. Now, the warmer temperatures we measured in the tank at the start of flight test pack. I will hold the animation here and go into some of the temperatures that we reported.

I zoom in now to the left side mid and half bays, the temperatures ranging from 123 to 145 on the left mid, moving up to the bay 2, bay 1. In bay 2 we have 128 degrees at the bottom and 119 at the top.

Now, we will pull back and examine the temperatures on the bottom of the center wing tank. The color scale was somewhat limited. so anything that is above 240 is represented by flash, and this on the bottom, that we range anywhere from 140-to-200 degree on the bottom surface of the center wing tank starts the flight test tank.

Now we examined some of the temperature measurement on some of the air-conditioning components. You see we ranged from 135-to-370 degrees.

We are now going to continue the test, continue the animation and follow the time of the test, and an inset showing flight test airplane will appear; however, because of the accelerated time, the motion of the airplane will appear to be erratic.

Now, the first vapor sample was taken on the ground during taxiing, and as we start to go, as we rotate, I'm holding animation. Notice the outside air temperature was 87 degrees. Continue now in the animation of the ascent of the flight test airplane. The airplane climbs. There is a slight relaxation of cooling of some of the temperatures in the tank. You notice a left path a left lid had gone from a bright read to more of an orange.

And when we cross 10,000 feet, the second vapor sample on this flight was taken. That data all the way, we show data at the same altitude is the TWA explosion. The test airplane passed the 14,000, that's when the third vapor sample was taken. The center wing tank pressure was measured at this altitude of 25-9 atmosphere .

We examine some of the temperatures measured at this altitude. You see in the rear, it ranges between 120 and 113, and 127 and 114 in the mid bays. The forward center of the forward two bays, it ranges between 115 and 120 degrees, and when we examined some of the measurements on the side of the tank, which are four inches from the side log, we see a slightly cooler temperature on the side walls, near the side walls.

We got out and examine a few of the

temperatures we made in the tank. We have a wing tip surge tank temperature of 68-to-78 inside tank 3.

And that concludes the animation.

Since that went by fairly quick, I want to review some of the key results from this flight test that we detected in this animation.

I noted in the color shading in the animation, maximum temperatures occurred in the center wing tank ullage immediately before the start of taxiing. Before I get too far here, I just want to mention, the animation that I showed and the animations that were showed yesterday, I just want to acknowledge the work of Mr. Doug Brady and Mr. Dan Vance, the NTSB Performance Division, for all their hard work in preparing these excellent videos. Also, Mr. Todd Frank for engineering the animation. I want to thank them for taking care of all of the animation; excellent results.

Examining the center wing tank ullage temperatures at the start of the flight test, which noted in the animation, when the ullage was at its warmest, we would be examining the temperatures going from the rear forward in the left aft bay, left mid bay, the center of bay 2 and the center of bay 1. We're going to be looking at the temperature measurements, the lower temperature measurements immediately above the floor in the center on the upper.

You see the left aft bay from a fairly good range from top to bottom, there is a fairly decent rating. The left mid bay, the maximum is about over 145 degrees. There was a similar rating at the bottom, getting considerably warmer than the ratings at the top. The forward two bays showing a similar rating, however, not as pronounced; however, there is considerable rating from the left rear side of the tank to the forward part of the tank, particularly in the left side.

And again, as I stated previously, that is the side that houses two air-conditioning units underneath the tank.

Now, this next plot shows similar measurements. We took temperatures on the test aircraft at 13,300 feet altitude. This condition best represents the conditions that existed in the center wing tank of TWA 800 at the explosion. We are looking at the same measurement location, different altitude. The left aft bay ranges between 120 and about 113. That is still a considerable rating in the left mid bay with maximum temperatures of 127 degrees at the bottom. The center of bay 2 shows a maximum of about 120.

Center bay 1, you see, has a similar distribution.

Some of the key findings from these simulations, first the temperature of the center wing tank went up to 127 degrees Fahrenheit, and that was in the left mid bay, 13,200 feet altitude. The temperature rating existed throughout the entire on ground taxiing and ascent portion of the flight, and some of those ratings were a fairly good size.

The vibrations we measured was well below the previously defined -- for any liquid fuel.

Now, we are going to briefly discuss the results of another flight test in the series. In this flight test two environmental control service units, systems, units were run for 90 minutes prior to take-off; 12,000 pounds of liquid fuel loaded into the center wing tank immediately before the start of taxiing. The same TWA 800 the central file was used for this flight, also.

Hence, the only parameter varied from the varied from the emulation flight to this test were the reductions in the air-conditioning pack operation time and the addition of the fuel to the center wing tank made before taxiing.

Now, this chart is a little busy, so I'm going to try to explain what everything here is. This is a plot of temperatures as a function of the lab's test time showing temperatures, the function of temperatures as a function of time for the two test flights.

These curves up here (indicating) represent TWA 800 simulation flight. The lower curves represent temperature measurements with the 12,000 pounds of fuel in the center wing tank. This comparison is for the measurements in the left aft bay and represents three vertical positions, the lower measurement, the central measurement and upper measurement.

You see the initial heat up portion in the simulation flight up to the start of taxiing and the lift off is noted right here, a slight reduction of TWA 800 altitude. On the flight with 12,000 pounds of fuel in the center wing tank, you see the same initial heat up of the tank of the ullage, and then the fuel is added to the center wing tank.

After the fuel is added, this lower probe is immersed in liquid fuel, and you see that the lapsed time of this entire test is much shorter than the reduced pack operation time before lift off. After the fuel is added and the taxiing, you see that the ullage remains somewhat constant.

Now, this next slide is a comparison of these temperatures of the center wing tank bay 2. Both test flights were at explosion altitude, 13,800 feet, and the results shown here is typical of all the bays. In the center of bay 2 the results from emulation flight is 50 gallons in the center wing tank. The lower probe measured close to 120 degrees; 12,000 pounds of fuel in the center wing tank at the explosion altitude; the temperature was reduced to about 96.

In this probe, the 12,000 pounds of fuel in the center wing tank was immersed in liquid fuel. The next upper measurement of the center probe was approximately 117, liquid fuel and the pack operation that was reduced to less than 85 and dropped. And the upper measurement shows similar behavior.

MR. SWEEDLER: Dr. Bower, just a point of clarification: These last two meetings, were they also immersed in jet fuel?

DR. BOWER: No, sir. These were actual ullage measurements.

MR. SWEEDLER: Thanks.

DR. BOWER: You're welcome.

Mr. Chairman, this concludes my presentation.

MR. BIRKY: Now, I'd like to go over to Dr. Shepherd and let him start on the laboratory measurements of Jet A explosions.

Dr. Shepherd.

DR. SHEPHERD: Thank you, Merritt.

We have to wait a minute to warm our computer. Someone kicked the plug out.

(Pause)

CHAIRMAN HALL: While we're waiting for Dr. Shepherd, Dr. Birky, will you and Dr. Bower sort of summarize for us, the presentations? What time is the fuel within the flammability range?

MR. BIRKY: I think we're going to come into that with a presentation, a brief presentation by Dr. Sagebiel and Mr. Jim Woodrow in terms of the significance of those temperature measurements, and significance - more significance - of the sampling that was done from that tank during the light process that data is involved, then I analyze and am available for discussion after Dr. Shepherd, I think.

How are you doing, Dr. Shepherd?

DR. SHEPHERD: I'm doing good.

MR. BIRKY: Okay.

DR. SHEPHERD: Okay, I'm ready to go. I apologize for that interruption.

MR. BIRKY: No problem.

CHAIRMAN HALL: As long as it didn't crash.

Presentation By

DR. JOSEPH SHEPHERD

DR. SHEPHERD: Good afternoon, Mr. Chairman, Ladies and Gentlemen:

The explosions Dynamics Laboratory became involved in this crash investigation in the Fall of last year at the request of Dr. Birky.

Since that time, we have carried out a number of studies on Jet A and the conditions of TWA's flight. Our work is still in progress, and as we meet here this week, my colleagues are carrying out experiments that will help us learn even more about this explosion that will tend to teach us how to prevent accidents in the future.

Today, I would like to inform you about the activities we have been involved in over the last year of our findings.

Our primary goal has been to assist the NTSB in determining the crisis of the explosion, the cause of the explosion, and in the process of pursuing that goal, we had to learn a great deal about Jet A. Despite over 30 years of using Jet A in commercial aviation and Jet 8 with Military aviation, two fields, I might add, are essentially identical, the amount of data on flammability and explosions is rather meager.

At the time we began our investigation, we acknowledged there were primarily three separate studies that have been carried out in 1967, 1970 and 1971. None of these studies dealt on the specific issues that are a part of the Federal investigation. For this reason, we have been compelled to carry out studies to unravel the physical chemistry of Jet A, the conditions in the center wing tank, the effects of the airplane operation on the flammability of the fuel, and finally, the initiation and the development of an explosion in the center wing tank.

My presentation will describe the key ideas and results of our studies in the Jet A flammability explosion. I use the term "our," because this has been a team effort. We have been together with our colleagues of other institutions, some of which is representative here today, all under the technical leadership of (inaudible).

The question is necessarily technical, and in some ways incomplete. It is important to note that in the process of our investigation, we have learned already a great deal, and I believe this knowledge will not only help us unravel what has been described as TWA 800, it will also benefit aviation safety.

Here is the plan of my presentation this afternoon. First, I would like to share with you the main questions you set out to answer last year when we began our investigation. Second, I will discuss the specific types of activities to be understood what the answer is. Third, I will present the key findings of our studies.

I would like to remind you at this point of some key facts surrounding this incident in order to motivate the public in our studies. From the crash investigation that you have heard about already extensively, we know that the initiating event was an explosion (inaudible).

There are three elements that had to be present, as Dr. Birky described in his introduction in order to have the fire and explosion. Those are fuel, oxidizer, and ignition. But these three elements are not enough. In addition, the fuel and oxidizer have to be mixed together in direct proportion so the plane can move through the mixture.

And further, the ignition source must be located within the flammable mixture.

Finally, at the point you have to burn the mixture, put the pressure inside the tank and build up. In the center wing tank, the fuel is necessary for the explosion. It was a residual amount, and I am going to use 50 gallons that is representative of the (inaudible).

However, the amount of fuel that was vaporized and present with gas mixed with air was unknown; but the oxidizer portion provided by the oxygen, which was 21 percent of the error -- if you look at the tank in my diagram, you will notice that the fuel indicated by the green material on the floor of the tank, some aspects of the tank are represented by the other (inaudible).

Some of the key things that we have already heard about in the previous presentations from the flight testing that are important as the heating underneath the tank, that those heated up the fuel. That resulted in the vaporization of the fuel, creating a fuel vapor.

Some of that mixture was vented out of the tank as the airplane climbed up to the altitude of 13,000, at which point there was an explosion, and the ignition source is at present not known. Other groups in the investigation concentrated on the ignition source, leaving us to consider the issues that are related to flammability, ignitability, and the build up of explosion in the tank.

As far as I know, the propagation of a plane to a complex structure like this is not going to (inaudible). Our work then is focused on the following issues: First of all, we needed to identify the amount and the condition of the fuel that was present in the center wing tank.

Second of all, we wanted to determine a measure of the ignitability of the fuel, and the conventional way to do that is to look at the minimum energy required to spark ignition. That doesn't mean that a spark ignited the explosion. It is for us to find the way to (inaudible).

Third, we wanted to determine what the maximum pressure possibly was.

Four, we wanted to examine issues related to the propagation of the point in the center wing tank. The last two items, of course, are key elements to the crash investigation. What did we learn from the wreckage around the ignition location? This speaks to the issue of, is there a characteristic signature that is developed by this explosion, and from that signature, is it possible to identify the location where the explosion --

I'm going to be speaking in this portion of my talk about the first three elements here, and I have a separate presentation a little later on on the propagation (inaudible)

So, let's consider then the mounting position of the fuel bracer on the tank. The key issue, of course, is why was the center wing tank flammable? And as we heard in Dr. Bower's presentation, it's the heating by the air-conditioning unit that causes the evaporation of the fuel, and in addition, the climbing of the airplane to an altitude of 14,000 feet created a more favorable mixture, with less air.

How the quantify that, how to express that in numbers allows us to evaluate this relative risk of hazards of propagating the center wing tank. Well, there are two ways we can go about that.

One is by direct measurement in a flight test, and that is done (inaudible). He is going to be speaking about that, and another way to do this is to carry out laboratory tests of the fuel and use results of the flight test and the modeling of the center wing tank to project the amount of the fuel vapor that is present.

So, it's necessary then to understand how much of that liquid Jet fuel was turned into vapor, and that issue in scientific and technical terms is, what is the vapor pressure of that fuel?

In addition to the vapor pressure, we have to know something about the chemical makeup of those vapors. Jet A is a complex substance that is well over 100 different types of molecules which all have different shapes and sizes, and therefore, we really needed to understand that. It has not been understood at that level of heat before, and we need to understand that and fly that airplane.

But, we did, and so, Dr. Woodrow at the University of Nevada, worked on that aspect of the testing.

Now, I'd like to say a little bit about flammability, just to recap what Merritt said earlier in my own terms and to emphasize these concepts because this is the key idea that we're dealing with here.

Flammability means that you have the right proportions of fuel and oxygen molecules in the plane. We measure flammability in terms of limits of flammability. That's given usually in terms of the amount of fuel. The amount of fuel can be expressed as a percentage by mass, or a percentage by volume, however you would like to do it.

The two figures down on the bottom show that as we added fuel to this mixture we progressed from a region where we don't have enough fuel to have combustion at the site, that's on the left-hand side. And there is so-called lower limit flammability, and there is a region in which the mixture is explosive, and then if we have too much fuel.

Our concern here today is with the lower limits of the plane. The vapor pressure in Jet A is very low. In fact, ordinarily, no one measures the vapor pressure in Jet A because the standard test techniques that are available for doing that, don't go that far. So, we had to develop special techniques to do that.

Here is the idea that we had in mind at our laboratory tests. We would use the data from the flight tests to give us the temperature at the time. We would measure the vapor in the laboratory. We would make some evaluation of the mixing and the evaporation that occurs within the tank during the climb, and that was done by engineering analysis by using the data from the flight test sample.

Then we would calculate the amount of fuel vapor. As a rule of thumb, the amount of fuel vapor, when you measure it in ratio to the amount of air, so you calculate this part we are going to call F, fuel air ratio, classic fuel vapor and classic air. We are now talking about just the content of this center wing.

When that exceeds three-hundredths mixture, how do we calculate that if we know the vapor pressure?

Well, the equation on the lower right-hand corner, it says that if we multiply the vapor pressure times the volume of the tank divided by the (inaudible).

That is why we have emphasized knowing what the vapor pressure is in our work. Vapor pressure is a very simple idea. Everybody is familiar with it because when you heat up your kettle on the stove, you make steam. The steam is actually little droplets that you can see. Ordinarily, you don't see vapors. When you go to the gas station, you smell them when you fill up your gas tank if you have some place where there is not a vapor recurring system.

The simple idea is, if you heat up the fuel that causes the few molecules to become more energetic, and they escape the liquid and they evaporate to form a vapor or gas. The collisions of those molecules with the walls produce a force, a pressure, and we call that vapor pressure.

Now, that's a property of the fuel. That means that if you have a certain fuel, and you have a certain temperature, you can measure that, but there are some complicating factors which are particularly important for this case. One is that, that is a very strong function of temperature. So, as the temperature changes by 20 degrees, you have a very large change in the vapor pressure, which is extremely significant for flammability.

The other property of a fuel like Jet-A is that as you increase the amount of fuel in the tank, the vapor pressure increases. That's not the case with simple substances, like water. The additional problem is that when the fuel sits out for a long time, or has been flying in an aircraft, sitting in the tank for 15 hours, that also can change the vapor pressure, and there is not a simple method to estimate or calculate the vapor pressure because Jet A is such a complex fuel.

At the time we started our investigations, there was no reliable data available, and so we set out to make measurements over a temperature range between zero and 60 Celsius, or 32 and 140 Fahrenheit, and we did that as a function of the amount of fuel. We varied it roughly from what would correspond to a half full tank to a center wing tank that only had 50 gallons in it.

the key thing about this is, we did this with a small amount of fuel. That hadn't been done in the past, but that's important because as you reduce the amount of fuel, you reduce the vapor pressure. You might think that the tank might not even be flammable because it had such a small amount of fuel in it.

Well, that's not the case, it turns out. The other thing that is important is understanding what happened to that fuel after it was loaded on the plane in Athens, and then it flew over to Kennedy, and then took off again. That's the issue of weathering. We will hear a little bit more about that later today.

I have already spoken about the business of chemical composition, and we will hear some more about that.

Well, all of those factor aside, we have gone into the laboratory, and we have measured the vapor pressure of Jet A, and these are the results. This plot shows the pressure. The units are a little bar. What does that mean in ordinary terms? Those are thousandths of an atmosphere. So, that scale ranges from zero to 20 thousandths of two-hundredths of an atmosphere. It doesn't seem like much, but that's all that it takes, in fact.

And the temperature ranges from 32 to 140 Fahrenheit. Now, what does that mean in terms of this problem at hand? Well --

MR. BIRKY: Joe, could you just explain what an atmosphere is so that the audience will understand that, please?

DR. SHEPHERD: An atmosphere is the pressure of the air right here in this room today. So, in common units, it's 14.7 psi.

The significance is that over on the right-hand side, you see an arrow that shows the range of flammable mixtures in terms of that partial pressure. We see that anything with a partial pressure above about 4 millibar would be flammable at 14,000 feet.

Now, if we then superimpose upon that range of temperatures that were measured in the flight test and reported by Dr. Bower in his presentation, we see that there is a very substantial overlap between those two conditions. So, we would expect, on the basis of this simple evaluation, that it would indeed be flammable.

Now, I have shown two sets of data here. The green points correspond to the half full tank, and the yellow points correspond to the 50 gallons, and we see in both cases that for the flight test temperatures between 100 and 140 Fahrenheit, we have a flammable condition.

That's what we estimate. Now, here is a little bit more quantitative application of that. If we imagine that we had 50 gallons of liquid fuel, that's about 330 pounds, if we work out our formula and we calculate how much we had in vapor in the center wing tank, that's about 4 pounds. Four pounds of fuel is a very small amount of liquid fuel. It's something about two-thirds of a gallon had to vaporize to form up. That would be at a reference temperature of 50 degrees C., which in the middle of the range of temperatures that were measured in the flight test.

Now, by comparison, the massive air in that tank is about 120 pounds at sea level, but when we go up to 13,800 feet, as Dr. Bower pointed out, the pressure drops down to 60 percent of the value at sea level, and therefore, we have a little bit less air. We only have about 70 pounds, and if we take the ratio of those two, then we can get a notion about what the fuel air ratio would be, and that's shown here on this figure (indicating).

The red line is the .03, the three-hundredths. That indicates the flammable condition, and I have shown as a function of temperature then, the fuel ratio to be predicted by this analysis, both at sea level and at 14,000 feet.

The important thing to note is that at sea level, the tank doesn't become flammable until the temperatures reach around 120 degrees Fahrenheit, or about 50 degrees Celsius, but at 14,000 feet, it becomes flammable when you've above 30 degrees Celsius or something on the order of about - I will give you the exact number here - 86 degrees Fahrenheit.

Now, those vapor pressure measurements are only a rough guide to explosion hazard. In general, the explosion hazard of a combustible liquid increases as the vapor pressure increases; but it's desirable and necessary to have a direct measurement of the flammability of this material, and as Merritt pointed out in his introductory comments, that's usually measured by a so-called flash point test.

Flash points for Jet A are typically in the range of 45-to-50 C. for the Jet A we tested in our laboratory, but we have found that a flash point is not a particularly useful concept for Jet A when you're considering ignition by sources like sparks, because the explosions can occur down to much lower temperatures.

That's because the flash point test is done with an open flame as the ignition source, and to start with an open flame over a very small hole, you basically take a cup full of fuel, and you heat it up from the bottom, a small cup, and it has a little hole in the top. Slide back a little slighter, and you just dip down the flame and see if there is literally a flash - poof. That's how the flash point test works. That test is very useful for ranking materials relative in hazard to one another, but it does not give you an absolute measure of the ignitability or flammability of fuel vapor.

So, we felt that explosion test inside of a vessel with fuel vapor and air under the conditions of the center wing tank at the altitude of 13,800 feet, that is a pressure of 6/10 of an atmosphere, and at the temperatures over the range which span what was measured in the flight test were important to do.

This is a standard data on flammability. There has been work done on this in the past, for example, this is the work that was done in 1967 by Nestor, but the important thing here is that his work used a tank which was one-quarter-to-one-half full, did not have the 50 gallon type equivalent, and in addition, he used a very strong ignition source. This is the ignition source of 12-to-24 jewels, and it was a repetitive spark.

Now, what does that mean - 12-to-24 jewels?

We spent a lot of time trying to give some sense to these numbers in terms of dropping objects and the energy that's available in your cellular pager and so forth. I would suggest that one way to think about this is when you have a short circuit in your household wiring, and you get a very strong spark and you blow out your circuit breaker. This is the sort of energy that can be involved in that.

So, we felt it was important for that reason to do new work in this area. We wanted to find the lowest energy that you needed to ignite a given mixture. We wanted to do tests with weathered fuel. So, we set out to do that, and the standard way of doing that is to use a small spark, a single spark, not a repetitive spark; to do it inside of a vessel where you can actually visualize what's happening to see whether or not you get ignition.

And to be able to examine the range of types of fuels, looking at fresh versus weathered fuels, and fuels from different sources. We have so far worked primarily on fresh fuel, although work on weathered fuels in progress.

This is the type of vessel that we do this experiment in. This is a rectangular steel box that's strong enough to contain an explosion. There is a pair of electrodes that are indicated here, and we discharge a capacitor which is charged up with some electrons through that gap, and makes a little spark. When the spark is strong, it's a flight flash. When the spark is weak, you can hardly see it. You have to turn out the lights to see it.

And we fill up the bottom of this vessel with a small amount of jet fuel, and then you can see there is some heating tape that's wrapped around it, and that heating tape provides the energy to warm up this vessel to the appropriate temperature, and when we do the experiment, it's inside of a box, and we control the temperature very carefully so we understand what we have. There are some connections up there on the top so we can introduce fuel and remove it.

This is a picture of what you see. If you look at the flame, using a particular kind of visualization, that's basically a very strong light source from the back, and there is a spark that occurs across the lower set of electrodes. The upper set of the electrodes were not used in this experiment.

And you can see a spherical shape which is growing from the bottom, and these pictures go from left to right, top to bottom. That is the flame itself growing, moving into the mixture, and as the flame grows, the flame becomes unstable, that is, you can see those lines on the surface and eventually down at the bottom it looks very wrinkled.

This was not done with Jet A. We have done some visualizations with Jet A, but it's very hard to do because it condenses on the windows, and we don't see a good picture. So, this was done with a simulant, which I will be discussing later in connection with the core skill test.

When we do these tests then, what we do is, we look to see if we get such a flame. We also measure the pressure. That gives us two ways to tell if there was in fact an explosion inside of the vessel, and then that gives us a point on our flammability diagram. And we do this over and over again. We had to do hundreds of tests to define flammability. It's very tedious to do when you do it with jet fuel because every time you do it, you have to take the jet fuel out. You have to clean out the whole container and start all over again.

If you don't do that, you're not going to get accurate results because even the very small amount of combustion you get every time you have a spark in there will change the chemical composition.

These are the results. This graph shows the amount of energy in the spark that was put in as a function of the liquid temperature, and we have data here from several different mass loadings. Our results indicate that the mass loading, that is, the amount of fuel, is not particularly significant for the ignition energy. That's one of the important findings that we have made.

The other finding that we made is that there is an extremely strong dependence of the ignition energy on temperature. This is a special type of plot. Every increment on the left-hand side is a factor of 10. That means the energy that we have at the top of this plot is 100,000 times larger than the ignition at the bottom.

So, increasing the temperature from 30-to-55 or 60 degrees Celsius, which corresponds with 86-to-14-Fahrenheit, increases the risk of explosion from a spark for a factor of 100,000. That's a very strong dependence. It's typical of fuel mixtures.

All of the previous testing has been done with over on the left-hand side of that graph, and as we see, this strong dependence has very significant implications for this investigation.

Now, I'd like to turn to the final topic of this presentation, and that is, looking at the maximum explosion pressure. The maximum explosion pressure, that is, the pressure that is developed when you have an ignition, determines the forces on the structural members of the wing tank, and those forces will then determine whether or not it fails.

We measured those pressures at Cal Tech in our explosion test vessels. That vessel that I just showed you was a very small vessel, but we have much larger vessels that we've also done this experiment on. The main parameters we've looked at are the fuel mass floating, that is, how full the tank is with fuel. We looked at the equivalent of 50 gallons up to a quarter full.

We have looked at this as a function of the fuel and air temperature and as a function of the amount of turbulence in the vessel.

This is the picture of the vessel, and it abuts the tank, if you can't tell the difference between me and the vessel. The result of those types of experiments are pressure time traces, which are measured with special pressure transducer and the digital recording system, and I have shown here results from Jet A at three different temperatures.

So, we have 40 degrees Celsius, that's 104 Fahrenheit, 50 degrees; that's 122 Fahrenheit; and 60 degrees, that's 140 Fahrenheit. You can notice the progression as you increase the temperature, the peak pressure increases.

MR. BIRKY: Joe, may I interrupt you. Can you go back to that slide, and would you do a comparison of those pressures with what the strength of the tank is so that the people know what that reference point is?

DR. SHEPHERD: Yes. Thank you, Merritt.

On the right-hand side in blue are shown the scale in psi, and this is the pressure increase, so we're measuring it starting from the initial pressure in the vessel, and I should point out, that was 6/10 of an atmosphere corresponding to the explosion altitude.

And I believe in round numbers 20 psi has been used as the strength of the weakest structural members, and we can see in all cases these peak pressures exceed that value, and in some cases, by more than a factor of 2.

CHAIRMAN HALL: More than a factor of what?

DR. SHEPHERD: Two or three.

This actually illustrates your point in a little bit different way. Here, I plotted the peak pressures as a function of the amount of liquid fuel that was in the tank, and I have indicated with this arrow over on the right-hand side the lowest failure pressures. These pressures are measured in a slightly different way. These are absolute pressures, not differential pressures, so the arrow is located in a little bit different location.

You can see that when you have very low temperatures, there is an effect of the small amount of fuel, but once we get above about 40 degrees C., or 100 degrees F., there seems to be very good agreement in between the two types of fuel loadings, and the pressures that we would predict for the temperatures, range of temperatures that were measured in the flight test, those peak pressures range from on the order of 50-to-60 psi, which is substantially higher than the failure pressure we were just discussing.

DR. BOWER: Excuse me, Dr. Shepherd.

DR. SHEPHERD: Yes.

DR. BOWER: On that previous plot, I'm having a little hard time reading those numbers on the right-hand side.

DR. SHEPHERD: I'm sorry. That's a poor choice of colors, I'm afraid, for that slide. It starts at 15. The next one is 29. Let me see if I can do this. It starts at 15, then 29, 44, 59 and the top is 73. So, the cluster of data points over on the right-hand side between 45 and 60 degrees Celsius, those all correspond to roughly 60 psi.

DR. BOWER: Thank you.

DR. SHEPHERD: At this point, I'd like to summarize our findings from our laboratory testing.

Fifty gallons is sufficient to create a flammable mixture in the center wing tank. You will hear more about this later on, but from our preliminary evaluations of weathered fuel, the weathering did not eliminate the flammability. It's quite clear from previous work on flight testing that the high temperatures in the tank drive evaporation, and the mixing within the tank - this is an important point that we will hear a little bit more about - the ignition energy is greatly reduced due to high temperatures in the tank.

And finally, the explosion produces sufficient pressure to create the observed damage to the center wing tank structure.

Thank you, Mr. Chairman.

CHAIRMAN HALL: Thank you.

I think at this point, we need to take a break. I assume there are other presentations; correct?

DR. BOWER: Yes. We have very short presentations. Then we go back to Dr. Shepherd on the quarter scale results.

CHAIRMAN HALL: Well, let's take a break until 4 o'clock. We will reconvene at 4 o'clock.

We stand in recess.

(Whereupon, a brief recess was taken.)

CHAIRMAN HALL: We will reconvene this public hearing.

We're in the discussion of the Flammability Panel. We have just completed one presentation by Dr. Joseph Shepherd at CAL Tech, and we have other presentations by the members of the Panel to follow.

Dr. Birky, if you would make the necessary introductions and lead us on.

MR. BIRKY: The next short presentation is by Dr. John Sagebiel, who will give us the findings on the vapor sampling during the flight tests.

Dr. Sagebiel.

Presentation By
DR. JOHN SAGEBIEL

DR. SAGEBIEL: Thank you, Dr. Birky. Good afternoon, Mr. Chairman, Members of the Board.

CHAIRMAN HALL: Dr. Sagebiel, I will have to ask you, as others, please bring your microphone close and speak into it clearly. Thank you.

DR. SAGEBIEL: Yes, sir.

My involvement in this program was involved with the flight tests that have already been described this afternoon by Dr. Daniel Bower, and exactly what I was doing is on this title slide here, the sampling and analysis of the vapors from the center wing tank of our test Boeing 747-100 series aircraft.

I think it's important to mention here that these were, as far as we are aware, the very first samples ever taken from the ullage of an aircraft fuel tank in flight, that is, as the plane was being operated, as described earlier. This is important because while we have experimental information about the vapor pressure and flammability of the fuels, as has been described just prior to my presentation, until we actually took these samples and measured them, we really didn't know exactly what was inside the tank.

What I would like to do then is very briefly describe what happened and what we found. We collected, as I have said, and has been described on the animation of Dr. Bower, that vapor samples were collected from the center wing tank during test flights. I returned these samples to my laboratory in Reno, Nevada, and analyzed them for fuel vapor components by gas chromatography, and those results then were compared to the fuel ignition data, much of which you have just seen in the prior presentation.

Again, as already described from the flight test animation, there were three samples per-flight. There were three flights on which we collected vapor samples. The three samples in each flight were one at taxi, one at 10,000 feet approximately during the climb, and one at 10,000 feet approximately during the climb of the aircraft.

This figure describes briefly the flight operation sequence, and I think it is important to describe this from the standpoint of what has been discussed as weathering or changing of the fuel. The zero time here along the X axis, this is elapsed time from fueling. This was when a small amount of fuel, as described by Dr. Bower, added to the center wing tank of the test aircraft.

The vertical axis simply shows the altitude at which the aircraft reached during each of the test flights. The first flight went to less than 20,000 feet. There was a gap in time. The first vapor sample flight, indicated here by this red arrow, took place about 28 hours after the tank was fuel. The second vapor sample flight here by this red arrow, which was the TWA emulation flight, took place about 35 hours after fueling, and the third vapor sample flight, which is indicated by this arrow here, was in excess of 60 hours, and the described flight excursions from the point at which the fresh fuel, or relatively fresh fuel, was added to the center wing tank.

I would like one more time, just for clarity, to describe the terminology that we're using here. We talk about, and Dr. Shepherd talked about a fuel-to-air mass ratio. This is simply the mass of fuel vapor divided by the mass of air that's found at any given point at any location that you want to measure.

A fuel-air ratio is analogous - I use the analogy here - to a rich-versus-lean operation of a car's engine. Those of you who have ever tuned your own car when cars had carburetors and fuel air adjustments, you could run the car rich, or you could run the car lean, and there are points, as was described earlier, under each of those where the fuel is too rich to burn or too lean to burn.

As also described, air has weight. Air weighs about 1-1/4 ounces per-cubic foot at the sea level, and it weights less at higher altitudes. The reason for this is described in this last bullet point is that air gets thinner at higher altitudes. With less pressure on the air, molecules are literally spaced farther apart. So, therefore, a mass of the given volume of the air is less.

The key findings that I'd like to discuss of my sampling and analysis program were that the fuel:air ratios increased with altitude and are flammable at 14,000 feet at that sample level, but are near or below the flammability at the sea level at the taxi samples where the flights began.

Fuel weathering, that is, changing the composition and therefore changing the physical properties of the fuel, did occur during the test flights. Even after 60 hours of flight operations indicated on that previous graph, the fuel vapors were in the flammable range at 14,000 feet.

This figure then describes these key findings. Briefly here across the bottom access indicated by the pointer, is the fuel-to-air mass ratio, and on the vertical axis is the altitude that the aircraft was at when the sample was taken.

The three flights are indicated as three different lines connecting three different points, the lowest three points here being at taxi, the middle three points here being at 10,000 feet, and the top three points here being samples taken at 14,000 feet.

I used for an example down here, the TWA 800 emulation flight, which has been discussed by Dr. Bower. As the plane climbed, you can see here, clearly, by the time it reached 14,000 feet, was up in the flammable range.

Now, what do I mean by that? This vertical black line at .03 fuel-to-air mass ratio is a guideline for the lower flammability limit of the fuel. The reason that the colors here are shaded in this region, going from blue to red, is that that is not a strict line. It is dependent upon other conditions, including the temperature and the energy of the ignition source, as has been described.

The temperatures that we observed here in the tank ullage, which was also reported by Dr. Bower, were between approximately 100 and 112 degrees Fahrenheit here at the highest altitudes, and somewhat higher between 100 and 123 degrees Fahrenheit for these samples at the taxi, or at sea level elevation.

The last feature I'd like to point out from this figure is this point here, the triangular point, and that is, the vapor sample from the third flight that we took vapor samples from on the 16th of July, as indicated in my graph that showed the excursions of the aircraft, this sample here was taken after 60 hours of flight operations, and the fuel had weathered. We did measure weathering of the fuel, and yet, it was still able to reach a fuel-air mass ratio in the tank under these flying conditions that was in the flammable range.

The significance of these findings, in my opinion, are clearly that the center wing tank ullage was flammable at 14,000 feet. I would also like to restate that these are the first samples of tank ullage that we know of that I'm aware of, that were taken during actual aircraft flight operations, and they do provide, therefor, the experimental verification that I feel is necessary for determining that the fuel, the properties of which can be studied in a laboratory, that those properties will actually result in a flammable fuel air mixture inside the tank during flight operations.

This work is tied very closely to the other work that's going on. As I said, this covers the actual fuel tank samples, vapor ullage samples, taken during the test flights in July of 1997. The results are similar to vapor pressure measurements, and I believe we've got a presentation on that coming up. And the understanding of the risk of the fuel air mixtures that we measured and found in the tank requires a knowledge of the fuel properties that are determined in the flammability testing, specifically, the ignition properties.

That concludes my presentation of the key findings of my work.

Dr. Birky?

MR. BIRKY: Thank you.

Before we go into Jim Woodrow's presentation, I'd like to just make sure we put on the record that this fuel that we're talking about in that center tank for the simulation flights was fuel from Athens, Greece. Roughly the same flash point of that was on the TWA accident. So, I'm not sure that was on the record.

Mr. Woodrow, would you please cover very briefly your measurements in this flight test?

Presentation By
JIM WOODROW

MR. WOODROW: Thank you, Merritt.

Good afternoon, Mr. Chairman, Members of the Board, and Ladies and Gentlemen.

May I have the first slide, please?

(Slide)

MR. WOODROW: As you can see from the title, my contribution to the investigation involved making laboratory measurements of the vapor behavior of jet fuel under center wing tank conditions, or simulated conditions.

Next slide, please.

(Slide)

MR. WOODROW: I would just like to take a minute or so and talk about the weathering. This graph is a bar graph. It looks rather complicated, but it's a graph of subsection carbon number versus relative concentration of vapor for the liquid fuel samples that were taken during the test flights that have already been discussed. Here, they are numbered 1 through 7.

Number 1 was the initial preflight sample that was taken. The fuel was taken out of an outboard wing tank, I understand, after it had flown in from Athens, and then loaded into the center wing tank of the 747.

Now, if you just move to the chromatogram, I will explain those subsection carbon numbers. This is a gas chromatogram of jet fuel vapor. As you can see, it's a complex mixture of hydrocarbons. Really, what I want us to focus on, the numbers down below; I divided that chromatogram into eight subsections, each one of which is characterized by a particular carbon number from C-5 to C-12, in other words, from Pentane to Dodecane.

During the test flights when the fuel underwent weathering, what happened is, that the lighter components from about C-5 up to about C-9 were lost in preference to the heavier compounds. The fuel vented out of the tank, but the lighter components were lost to a greater percentage than the heavier components. So, the fuel became enriched in the heavier components.

Let's go back to the previous slide, and I'll show you what I mean by that.

(Slide)

MR. WOODROW: So, if you look closely at this bar graph, I just mainly wanted to point out that when you look at the test flight samples, the solid black bar is, again, the preflight sample. The subsequent bars show for those subsections, or carbon numbers less than 9, you can see a definite decline in the relative concentration of the vapor with successive flights. So you can see that the fuel was depleted in lighter components.

But if you go to about C-9 and above C-9, you can see a relative increase in the heavier components in the vapor. This is what we mean by weathering of the fuel.

Let's go to the -- okay.

(Slide)

MR. WOODROW: I want to cut to the chase here and just show you the results of measuring the vapor concentration of these test flight samples. This is a plot that is similar to the one that Dr. Sagebiel showed. It is a plot of fuel:air mass ratio against a fuel temperature and degrees Fahrenheit, and again, the fuel:air mass ratio is just simply the mass of fuel vapor divided by the mass of air containing that fuel.

I show on this plot on the extreme right line is an example of what unweathered fuel had looked like. This is at 14,000 feet, by the way. All the lines that are clustered together are made up by the test flight samples 1 through 7 showing they are clustered. The vertical line at .03 fuel:to air mass ratio is a lower flammability limit, and I agree with Sagebiel, it is not really a hard and fast line of demarcation; it's a blurred area.

But I have it here as a reference point mainly to show that although compared to the unweathered fuel, the test flight fuels underwent weathering; it's very obvious. They still were flammable at 14,000 feet, and at temperatures ranging from a little over 105 degrees up to 140 degrees of the test temperatures.

I tried to reproduce the temperatures in the lab that were observed in the aircraft.

(Slide)

MR. WOODROW: The next slide just shows some of the same data, a comparison between 14,000 feet and sea level. You can see how important it is, not only the temperature, but have the fuel at altitude and the fuel actually is flammable at a lower temperature at 14,000 feet.

Next slide, please.

(Slide)

MR. WOODROW: So just briefly, summarizing the findings, we observed the fact that jet fuel exposed to flight conditions showed weathering effects, or what we call differential volatilization compared to unweathered fuel, and the weathering occurred in a characteristic way, preferential losses of the lighter components, and accumulation of the heavier components.

This resulted in an overall lowered vapor pressure for the fuel totally, showing an increased average molecular weight. But despite these compositional changes, weathered jet fuel is still flammable at 14,000 feet, and that temperature is greater than about 104 degrees Fahrenheit.

(Slide)

MR. WOODROW: Then the last slide, Dr. Sagebiel mentioned -- I'm sure there is a slide of his vapor samples. I just wanted to make a comparison here, showing how the laboratory measurements stacked up against the measurements made by John, and this slide shows that, again, for fuel to air mass ratios plotted against altitude and feet.

The liquid test samples went through seven, and then vapor flight samples, 1 through 3, and the extreme right line represents the preflight, the initial preflight sample. As you look to the left, you notice how all the various samples cluster. We don't need to look at the individual lines, but the point here is, they all cluster together.

I used my 122 degree Fahrenheit data for the laboratory compared to John's test flight, vapor samples, and they compare very well, indicating that the laboratory simulation is very reliable.

That's all I have to present at this time.

Dr. Birky.

MR. BIRKY: Thank you.

I think we will go on to the quarter scale measurement so we get them on the record, as well as then go on into the modeling, and we will then go back and ask questions later on.

So, Dr. Shepherd, would you go ahead with the quarter scale work.

Presentation By

DR. JOSEPH SHEPHERD

DR. SHEPHERD: Thank you, Dr. Birky.

I would now like to present our program that we carried out on scale model testing of explosions inside the center wing tank. This work has been a cooperative venture between our laboratory, Applied Research Associates, Rocky Mountain Division in Denver, Colorado, and the Safety Board.

There has been a large number of individuals involved in this effort. In addition, down at the end of the table here, the modelers have had a significant contribution to that, also, I would like to acknowledge.

Let's turn that off.

Okay. Why did we carry out quarter scale model tests? We wanted to examine combustion issue which were not addressed in our laboratory testing.

Laboratory testing was done in small vessels, simple design, simple construction. When we wanted to look at some other issues, I would like to point out, first of all, in our testing, we have used a simulant fuel instead of Jet A. This was done for a number of reasons, which we can touch on a little later on in the questioning period.

We have planned a series of about 30 tests. They are now about 90 percent complete. We have made a number of photographic and electronic measurements in these tests, and we are making comparisons with what we see in laboratory test computations and wreckage from the crash.

I would just like to point out some of the things that we think are important about the modeling tank. First of all, we need to include all of the beams and the spars of the tank, partial ribs. The water bottles in the front are important from a structural point of view.

You recall that the first bay is a dry bay, and it is not filled with fuel, or will not contain a fuel air mixture. And in addition, we have a venting system, which is, again, indicated schematically, and it's not strictly speaking, correct.

And finally, in the examination of the

wreckage, it was found that there was a manufacturing access panel and spanwise beam 2 that appeared to have been ejected early on in the accident, and the failure of that, we felt, was important to the model.

What does our scale model look like? Well, this is an attempt to convey a sense of the size. It is one-quarter scale geometrically, that is, every dimension has been scaled down. We have not preserved all the features. Here is a list of some of the things that we have had to include in order to do this experiment.

We have transparent sides on the tank. We have transparent partial ribs. That's so that we can see through the tank and have a visualization of the propagation of the flames, and we are able to adjust the strength of the beams and spars to examine the effect of failure on the combustion.

This is what the actual test fixture looks like. It's constructed of heavy steel so that we can re-use it and do a number of tests.

The key idea here is, this is an engineering scale model; it's not a scale model in the sense of a plastic model that you buy and put together that resembles a car or a plane. The key thing here is that the dimensions are scaled appropriately. The linear dimensions are one-quarter scale of the full values. The areas are one-sixteenth, and the volumes are one-sixty-fourth.

The flames speed and the maximum pressure will be the same as in the full-scale values. The event, however, will happen in one-quarter of the time required for a full-scale event. The most important aspect of our scaling is that we expect a sequence of events, the pressures and the gas motion to be replicated in the scale model for a given ignition location.

And now, we'd like to show the video. Here are some of the things that we felt were important to reproduce: the geometrical proportions, the flow areas corresponding to the various openings between the bays and the tanks; the volumes of all the bays; the amount of fuel vapor. We chose as a standard condition the amount of fuel vapor that you would have at a temperature of 50 C., and most importantly, we also wanted to model the altitude effect.

We used a scaled amount of liquid fuel in some of the tests corresponding to the 50 gallons in the center wing tank, and a test in which we had weak beams and spars, that is, those partitions failed and were ejected from the tank. We scaled a mass of those and the water bottles.

The parameters that we varied in our test have been the number of bays that was done in order to provide the information that's important for our validating the combustion models. The operation of the vent tubes and the stringers, that's to investigate the role of venting during the combustion, the strength of the beams as spars, this is not designed to study the actual failure process, but, rather, to understand the effect of the failure process on the combustion.

In addition, we have varies the vapor fuel amount, the presence of the liquid layer, and most importantly, the ignition location.

We have done four series of tests. the Alpha series, we had no venting. We used all strong beams and spars. Beta series, we used venting, all strong and varied ignition location; and the gamma series was vented. We had weak beams and spars. That means that they all would fail when the pressure reached about 20 psi. We varied the ignition location, and we also added liquid fuel in some of those tests.

Finally, we have done a configuration which we call part strong, which corresponds to best estimate of the failure of sequence, as determined by the sequencing analysis group, and the crash investigation that corresponds to failure of front's bar, spanwise beam 3, and the manufacturing access panel.

We varied the ignition location and the amount of liquid fuel, vapor fuel amount, and we planned to look at venting into a model forward cargo department.

At this point, I would like to show you a video of some of our tests that we've done. This video is going to show a description of the quarter scale facility, and then it's going to show the results from two tests, Test Number 4, which consists of all the all strong configuration with ignition, and what we're calling Bay 5 in Test 21, which was an all weak case with ignition in Bay 2 and liquid fuel.

First, I'd like to illustrate what I mean by the number of bays, and so this is our schematic. The numbering roughly corresponds to the numbering that Dr. Bower used in his explanation. We see that Bay 1 is in between spanwise beam 3, and spanwise beam 2. Bay 2 is between spanwise beam 2 in the midst bar, and so on. The ignition in Test 4 was carried out in Bay 5, which is the left aft bay.

The other tests that we're going to be seeing is Test 21. The ignition in that case was carried out in Bay 1 in all of the features, the partial ribs, spanwise beam 1, missed bar, spanwise beam 2, spanwise beam 3 and the front bars are weak structures that will fail around 20 psi. This test also contained liquid fuel between the bar and spanwise beam 3.

(Whereupon, a video was played.)

DR. SHEPHERD: That concludes this portion of the presentation, Merritt.

MR. BIRKY: Joe, did you have any final comments that you would like to make on that series of tests in terms of any conclusions you'd like to make on that?

DR. SHEPHERD: Yes, I have some concluding remarks that I could make at this time, Merritt.

I think the most important aspect of our testing is that we have found that combustion occurs in a complex fashion within a center wing tank, but in all cases, the pressure within the tank increases quickly, once the flame has propagated through the bay in which ignition has occurred.

The beams and spars in the front of the tank failed and ejected immediately after the failure pressure was reached. This behavior is, of course, sensitive to the amount of fuel vapor, and we are continuing testing on this aspect; another problem.

A fire ball is produced when spanwise beam 3 and the front spar fail. This could produce an increase in pressure within the fuselage, and again, testing on this aspect of the problem is in progress.

It appears that the damage observed in the crash wreckage could have been produced by ignition in any of the bays. Our testing has been designed to examine specific features of the explosion that might be produced by various ignition locations, and that testing is still in progress.

MR. BIRKY: I'd like to ask just one question, and then we will move on, I think, to the modeling effort of it.

I want to make sure we clarify this question of simulant fuel so that people understand that Jet A was not used in this test, except for the liquid fuel. Would you comment on that a little bit, Joe?

DR. SHEPHERD: Yes. If we could have my computer screen back, I can show you what we did in order to simulate the Jet A. There are a number of problems trying to do a heated experiment at a lower pressure than ambient, and for that reason, we chose to find a combination of fuels. In this case, it was a mixture of propane and hydrogen.

We adjusted that combination of fuels to match the pressurized and flame speed in Jet A that would be created from the liquid layer scale to 50 gallons in the center wing tank at 50 degrees C.

This graph shows the results of experiments that we did in our laboratory at CAL Tech in our 1,100 leader vessel. You see the red line represents the results from testing with Jet A at pressure of 6/10 of an atmosphere, and the blue line is the results of doing testing with a pressure of about 8/10 of an atmosphere, which is what we have at Denver at the test site with our simulant.

The simulant and the jet fuel are fairly closely matched, and more importantly, the initial development of the flame, which is measured by the flame's speed, is matched precisely.

MR. BIRKY: And this is done at 14,000 feet equivalent?

DR. SHEPHERD: Yes.

MR. BIRKY: I'm sure there are a lot of questions, but I would like to get into the quarter scale modeling at this point, if I could.

For that inquiry, I am going to turn it over to Mr. Dennis Crider for starting that part of the program.

MR. CRIDER: Thank you, Dr. Birky.

Presentation By

DENNIS CRIDER

MR. CRIDER: Good evening, Mr. Chairman, Ladies and Gentlemen.

CHAIRMAN HALL: You've got to get closer to the microphone, please.

MR. CRIDER: Yes, sir.

Good afternoon, Mr. Chairman, Ladies and Gentlemen.

I'd like to start off this series of questions on computer simulation with a series of questions to Dr. Paul Thibault.

CHAIRMAN HALL: Now, we've completed all our presentations; is that correct, Mr. Birky, or not?

MR. BIRKY: Yes. We have completed the presentations at this point. We have not completed the questions about some of the issues on the experimental testing yet.

CHAIRMAN HALL: I have some questions, but I'll wait until we get all the presentations and questions done.

MR. CRIDER: Dr. Thibault, what is computer modeling?

DR. THIBAULT: If you could show the first slide.

(Slide)

DR. THIBAULT: I'm going to try and explain that in most simple terms. Computer modeling is a method that is used for a live variety of applications since the development of computers obviously. Basically, if you have a problem, whether it's an explosion or any other type of problem, you need to be able to come up with some physical laws to describe the processes for this problem.

Physical laws. Well, what are physical laws? Newton's law of gravity would be a physical law. Einstein's theory of relativity is a physical law. How do you get these physical laws? Often by experiments. If you are as smart as Einstein, you don't need experiments. You just come up with a theory and let the experimentalists prove it.

Most of us at this table are relying - at least at this corner - on experiments. But you come up with these physical laws. These physical laws is for who comes up with them, they are typically engineers and scientists, and the first thing they do is to write these laws in the form of equations. This is really their working tools.

Now, if the problem is simple, you can take those equations and just solve them on a piece of paper and you've got the answer. If it's more complicated - and certainly, this problem here falls in a much more complicated category - that will not work easily, and you will need the computer to solve the equations.

MR. CRIDER: How do you go about computer modeling in this case?

DR. THIBAULT: Well, as we know from experience, computers are powerful, but not very smart. We need to tell them how to solve these equations. They don't really know what we're giving them; they just know that they've got to solve them, and we give them a recipe to solve them.

So, we have a group, often mathematicians, that come up with methods of solving these equations, and they develop what we call numerical methods. These are numerical because we're talking about numbers, and they develop methods how to crunch the numbers in the computer.

Once the computer gets these instructions, solves the problem, puts out an output in the form of numbers, graphs, and often in computer animations.

If you show the next slide, I will kind of go over quickly how that gets done for explosion modeling.

(Slide)

DR. THIBAULT: Explosion modeling certainly falls in the category of multi disciplinary modeling, and therefore, quite a wide group of scientists are involved. An explosion basically involves combustion. It generates flow, and if the vessel or whatever structure is weak, then you get damage.

Usually, you're interested in explosions because there was damage, so usually for accident analysis, all these three aspects come into play.

The combustion part, well, all you really need to know about it is that to understand it is that you start with a group of molecules, let's say, hydrogen, oxygen, or in this case, we had fuel and air. You break up the molecules. That's usually done by the ignition source, and then these molecules break up and re-form into new molecules usually water and CO2, carbon dioxide.

What's important as far as what happens to the structure is the energy that is put out when these new molecules are formed. This energy goes into the flame, and as the flame travels, as it is liberating energy right at the flame front, it is heating up the gas, and because it's heating up the gas, it expands the gas, and because it's expanding the gas, it pushes the unburned gas ahead of it and makes that gas flow.

If there happens to be an orifice, an obstacle, or even if you're in a closed room, you're going to form a very complicated flow when that happens. The modeling of flow, just so you can understand some of the terminology we're going to use here, is usually called fluid dynamics.

The word "fluid" comes because we're modeling flows. Gases and liquids are considered fluids because they flow, and that's pretty much it. And they can flow into very complicated structures with low pressure zones pretty similar to when you wake up in the morning and look at your satellite weather picture in hurricane season, and you see all the water seas; that's fluid dynamics.

Now, why we call it dynamics? It's because it's changing with times, therefore, the word dynamics. So, we've got fluid dynamics. In this case we are changing over days or changing over milliseconds.

Now, the other important effect of the flame as it releases energy and causes this gas expansion, is that it produces pressure. Of course, that's what the structure is vulnerable to, is the pressure that's generated.

Structures are usually made out of solids, such as metals, and metals, solids, usually do not flow. So, they tended to form and break, and we need another group of models to handle them. Since we call them solids, then we usually call the fuel that we look at, the deformation and fracture of solids is usually called solid mechanics.

These are the three main ingredients that we need to look at for the model.

If you go into the next slide.

(Slide.)

DR. THIBAULT: How do you go and put this on a computer? I basically described some of the phenomena in very simple terms here, but we need to put this into the computer. We have three areas that we need to consider here: The combustion, obviously, which is the source of all this; the fluid dynamics, because of the flow that is produced; and the solid mechanics because we are wondering what's going to happen to the structure, or understand what's happening to the structure.

Again now, we've got to put all these laws of these three different disciplines into a computer. Pretty much what we do is, again, we go to numerical methods. People come up with basically numerical recipes to put these equations -- and these equations are now getting quite complex. Each one of these fields have quite a long list of equations. And you want to be able to put those in the computer.

If you combine fluid dynamics and numerical methods, in other words, that the scientist engineers and the mathematicians got together and they're going to put this into the computer, they're going to come up with a discipline that we call computation fuel dynamics, CFD.

CFD is a field which pretty much started as computers came out, but I think people have heard more about it since, I would say, from the mid-Seventies when computers got particularly useful to people, and the algorithms, let's try a numerical recipe; got sophisticated enough that we could put these on a computer, and it would give us an answer that is useful to us.

So, what we're going to talk about modeling is going to be computational fluid dynamics. What I said is all you really need to know to understand what it's trying to do. We will get into it a bit later on with other people, exactly how that's done.

Solid mechanics is the same thing. Combine solid mechanics and numerical methods, and you come up with a term that's called computational solid mechanics, CSM. You take those and you combine with combustion, and you got yourself a program otherwise known as a code, otherwise known as most of us understand it, as software.

Take that software, put it in the computer, and you get results.

MR. CRIDER: Excellent. What are the objectives in this case?

DR. THIBAULT: Well, as has been mentioned, there is one primary objective, which is the third bullet on this flight, the term possible ignition location. There are other objectives before that, though, as Dr. Shepherd mentioned, the modelers were to derive some input into quarter scale experiments to get an idea of what would kind of experiment would be meaningful.

Now, we have to give credit to Dr. Shepherd here. There wasn't much to be added. Most of it came from his head without CFD, but there were some areas which he will mention that the models did contribute to.

Another important aspect of CFD and explosion modeling, let's say, is to provide inside in the physical processes. You can have an experiment. You can make some measurements. You can have a bit of visualization, but it might still be difficult to figure out exactly what happened. Computer modeling offers you some advantages there, but as far as this group is concerned, the main objective was to determine the ignition location in the accident.

MR. CRIDER: Are there some things that you can do with computer modeling that would be difficult to do experimentally?

DR. THIBAULT: I think where they differ is more in the scope of the input and the output, and when I say "input," what we put into the computer model and what we get out of it, the computer is incredibly powerful generating data, and it's also not too picky the data you put into it. As I said, the computer is not that bright in that sense. You put in whatever you want, and you get whatever you want. But it gives you that flexibility. You can pretty much put in anything; you can pretty much get out anything.

As far as the input, some of the work or some damages, certainly the geometry, putting in different geometries in an explosion model is relatively simple, and certainly not very costly because you don't have to manufacture anything.

I think another important aspect, though, is the initial pressure. If you want to do, let's say, a scale model on the center wing tank, you would have to go to a certain elevation to get at the right pressure. With computer models, we don't need to do that. We just change the number and call it the initial pressure, and we run the calculation.

We know from the flight test data that the fuel concentration was not uniform in the tank. That is one area where it is trivial for a computer model to change that and to put in whatever sensible value that might be.

We can change the ignition location, but to be fair, it's just as easy to change ignition location in an experiment, so that's not a big advantage. Structural failure criteria, that is an important issue here. The failure of the partitions was not a simple process. The criteria for failure, there is a criteria if a panel fails without the other panels failing, but there is another criteria if an adjacent panel failed.

So, the criterias for failure can become quite complex when you actually go in to analyze the accident. That is something that the computer modeling can help you.

Probably one of the most important benefit is that you can go to a larger scale without any additional cost. The computer doesn't care whether you're modeling something that's 2 inches in dimensions or 5 miles in dimensions. It doesn't care. So, there is an advantage there.

On the output, the usual thing you get from an experiment, you get pressure. In experiments, you can also get temperature. There are other variables, though, that become more difficult to get from an experiment, flow velocity, for example; how fast the flow is moving. How turbulent is the flow? Is agitated is the flow? How unstable is it?

Also, the chemical composition during combustion. So, those are some of the areas, as you go down that list on the bullet, modeling can offer you things that become more difficult for experiments.

MR. CRIDER: Well, as you said, the important things, of course, is since you have to be very careful on the coding, how do you go about validating the code and the work in general?

DR. THIBAULT: Well, that's an important issue. As I said, the problems with computers is that they have no idea what you're putting into them, and therefore, they will take anything and give you answers. You have to validate these codes before you use them for a practical application.

I'd like to answer that question in two ways: There are different types of validation if you come up with these laws and you come up with equations. Now, you have to understand that any law or any equation you write down, is an approximation. It's a human description of what that human thinks is happening in that physical process. That's all it is.

And the better we get at it, and the more generations we go through, we get better answers.

MR. BIRKY: Paul, may I just interrupt you a minute, and ask a question? What do you mean by "validation?" To check with reality? Is that what a validation is?

DR. THIBAULT: That's as good a definition as I've heard, yes.

MR. BIRKY: Okay, thank you. Go ahead.

DR. THIBAULT: The first phase is validation of the equations; in other words, of the equation solver. This is where the numerical methods people, those mathematicians, gave you these recipes to solve your equations. You got the equations, and you want to know that they're solving those equations properly.

There are different ways of doing that, and I won't got into detail, but that's basically saying that if I have these equations, am I solving them properly? Now, this doesn't mean that you've got right answers. This just means that you solved the equation you thought were correct properly. This does not mean that your equations were correct to start off with.

To understand whether the equations you start off with were correct, you've got to go to the next step and compare it with experiments. Even the greatest had to go through that. No matter how intelligent you are, nobody will believe you until you have experimental validation, which means for you to take a problem, calculate on a computer, and have somebody, preferably independently, do an experiment.

Another way is to compare with other codes, programs, software, that try and model the same thing. This is very important because different programs may use different models, or maybe are more accurate for the models that they're using. So, that adds an additional check and balance.

You have to accept that when you go through this type of method, both experimental and calculations, you never take for granted that the results you're getting are totally correct.

No experiment is perfect, and no calculation is perfect. The more that you try and compare between models and experiments, the greater level of confidence you have that you're getting the correct answers. Once you've gone through that stage, then you want to go to the right column there which is the validation stages. There are two ways of validating by comparing with experiments.

I mentioned fluid dynamics; I mentioned computational solid mechanics; I mentioned combustion. And each one of those, these are large disciplines, and each one of those, there are many submodels. You want to check each one of those individually to make sure that each one of those is correct because you could have lots of models and get the right answer for the wrong reasons.

So, you must check that each model is correct, the submodels. That's usually done with small scale experiments quite similar to what was done at CAL Tech in their laboratory, looking at the burning properties of the fuel. Once you are confident that your submodel is correct, then you can go into a validation exercise for a small scale geometry, and if you did all right there, then you can proceed to the full scale geometry.

MR. CRIDER: Okay. Excellent. Thank you, Dr. Thibault.

I now have a couple of questions for Dr. Kees Van Win Gerden. If you would, sir, could you describe the physical processes that must be included to model this problem?

DR. VAN WIN GERDEN: Yes, okay, I'd love to.

Mr. Chairman, I've seen that many people have problems with my surname, so if somebody wants to address a question to me, they can easily call me "Kees," which is my first name. It's probably easier, or "Kees," if you pronounce it in the American way.

What I would like to do is, I would like to go back a little bit and go into the phenomena again to answer this question, Mr. Crider.

My first slide.

(Slide)

DR. VAN WIN GERDEN: Yes. Thank you.

So, the problem of a gas explosion is that the combustion creates combustion products, and they are hot, and if something is hot, it will try to expand, as you all probably know. Also, when you feel hot, you want to expand. You want some space. The same accounts for combustion problems. They will expand.

If you try to hamper that, or try to limit that expansion, you will get pressure build up. So, the gas explosion problem is causing pressure. This pressure is a result of the rate of generation of combustion products, which is, in fact, the rate of combustion, or the burning speed; and on the other hand, how fast can you get rid of those combustion products, or any gas in your room while the explosion is occurring.

So, that will cause the final over pressure, those two contracting factors.

The rate of generation of combustion products is determined by what sort of gas do you have? What sort of reactivity has this gas? How fast does it burn? And it also depends on what is the concentration of this gas in your gasometer. So, if you have a very low concentration of gases, it may even be possible that it is not flammable. It cannot burn, or if you have too much, it might also be possible that it doesn't burn.

In between those two ends, there is an area where it can burn, and it will burn, depending on the concentration. It will not burn everywhere as fast, If the concentration is fast, as you may think that it does.

There are also other factors as we mentioned that have been very important. I will come back to that.

On the other hand, the pressure is also determined by the degree of confinement. If you have an explosion in the open air, generally, you will generate hardly any pressure. You will only hear some sort of a puff, or whatever sounds you want to make. It's not a bang.

So, if I can go to my next slide where you see the two limits.

(Slide)

DR. THIBAULT: You have a mixture of masse and air, not Jet A, but masse and air, typical pressure you will get in a closed bomb because of this expansion which you in fact hamper. You do not allow it to expand; you try to keep it together. So, in a closed bomb, as you can see on the top side, you will get an over-pressure of typically on the order of eight bars, which is 8 times 15 psi; you know exactly how that is.

On the other hand, if you just allow it to expand, you will get an increase of volume by a factor of approximately 8. It means that you needed space by approximately a factor of 8. That means that something else had to vanish that was the air which was originally there. It had to be pushed away, or, in fact, the mixture which is there.

So, those are the two limits. At one end, you have a closed vessel which causes 8 bar, and on the other hand, you have something which is no pressure, but just a volume expansion.

Go to the next slide.

(Slide)

DR. THIBAULT: There are some factors which determine the combustion rate, and one of them is the gas type. In the top right corner, you see a vessel which is a in fact general, which is closed on all sides. It's only open at the right side, and there are some baffles inside it.

If you prepare a mixture of hydrogen and air there, you get a typical pressure of about 8 bars. although it is open, the pressure can be released. If you do, you may test with messe or essane or propane, you get much lower pressures, which are in the order of perhaps tenths of a bar or two-tenths of a bar, much lower. So, this is the gas type.

These mixtures which are shown here are optimal. That means they are the fastest burning mixtures you can prepare with hydrogen and air, or with messane and air, or whatever is shown on this graph. This concentration dependency is shown on the next graph, experiments which were done in the same vessel.

Could you please show me the next slide.

(Slide)

DR. THIBAULT: Thank you. This slide shows how the over-pressure in the same vessel would vary with the concentration. So, only at one concentration, which is the optimal concentration which in our terms, is called a stogemetric concentration. They will get the pressure, which is the maximum for this particular one for about half-a-bar.

But if you move away from that concentration, you get lower pressures. So that has to be modeled, as well, by your combustion code, or your code which handles this kind of problem, this gas explosion problem.

Please move on to the next slide.

(Slide)

DR. THIBAULT: We are running into this other combustion rate increasing factors, which is turbulence, a very important one, and there is also something called combustion instability; but I don't to go into that. But Turbulence is very important. In fact, turbulence has been already shown and mentioned by others.

It is generated by the explosion itself, and I want to go briefly into that process so that you clearly understand what is going on, and how complicated this process is.

My next slide will show you what is happening when you have turbulence.

(Slide)

DR. THIBAULT: Turbulence is a tornado, or maybe generated by the flame itself. It is mixing of air, like in a river. It is a mixer, and what it does is, it mixes the unburned gas with the burned gas, or it causes perturbations on the flame surface. That's on the left side, or the mixing is shown on the right side.

What you effectively are doing is, you increase the surface area of the flame enormously, and it burns much, much faster. So, it has to be modeled, as well. So, how does a flame or a combustion wave generate turbulence?

On my next slide, we will see a box, a channel again, with some opticals.

(Slide)

DR. THIBAULT: This channel is closed on all sides. It's only open at one end, which is on the right end, so if you ignite a mixture, a flammable air mixture in this box, you start a combustion. This combustion is initially going very slow typically in the order of half-a-second is the reaction speed. That is the speed with which the flame eats itself through the unburned gas. But it generates combustion products, which are hot and want to expand. That happens behind this reaction front, behind the flame. They expand and they need a place.

If they need a place, something else is to vanish, and that is the unburned gas ahead of the flame. So you get a flow ahead of the flame. Well, obstructions are shown here, these cylinders. You will get these tornados, disturbance being generated.

As we saw, turbulence enhances the combustion rate. It means it starts burning faster when the flame gets there. That means that you generate more combustion flow per-unit of time. They want to expand, so they expand, and that means there is more expansion for unit of time than there was before. That means it needs more place and a flame, or the unburned gas ahead of the flame will start flowing even faster.

So, you get more intensive turbulence ahead of the flame, as a new obstacle. When the flame gets there, it starts moving or burning even faster. So, it is in fact accelerating itself, and it goes faster and faster.

On my next slide, you will see how this works if you put it into a diagram.

(Slide)

DR. THIBAULT: So you've got combustion,

which is the block on the left side which causes an expansion flow, as explained. This will cause obstacles, as shown in this channel, turbulence, or at the walls you can also get turbulence, or as you have in the center wing tank through these passageways. You generate turbulence at the passageways.

Due to that, the flame will start burning faster gyrating through an expansion flow. You get higher or more turbulence, et cetera, et cetera. So, it's going through this loop all the time and it's accelerating itself. So, as Dr. Shepherd showed, initially, the flame burns very slowly, but once it gets turbulent, it happens in no time. So, this is the process we have to follow.

I have a video now which I would like to show you. It just shows exactly what is going on, the effect of an explosion in the channel. The first pictures which are shown show a box, as shown in this overhead of mine.

First, you will see that the box is empty. There are no obstacles inside, and you see how the flame will propagate through this box. So, there is the box, and we ignite it from the left side of the closed wall, and here the flame starts to burn, and because of unburned gas being pushed out of the box ahead of the flame, you get also that the flame can move out of the box, as we also saw in his experiments, especially the second one.

So, to use obstacles in this box, there you get disturbed generation, and you will see that the flame suddenly accelerates, and not only that, you get also a violent explosion outside, because everything now is very turbulent generated by the combustion itself.

So, this is the kind of program we have to model, though the same kind of process is in fact happening in the center wing tank. So, he prepared the two, which you see, a very strong difference between the two. You see that the one without the turbulent generation is going very slow, whereas, the one with the obstacles and the low turbulent generation goes very far.

It can even go one step further. It could introduce some perforations in the top of the box. If we do that, the combustion products do not expand only in the direction of the obstacles any more, but they can expand in fact up in the upward direction, as well.

Then we in fact tame the explosion considerably, if you would be interested in that. So, it is just to show how complicated an explosion is, and how difficult it is to model that. So, here are the perforations. You've got a flame which is now in fact not propagating very fast any more.

The combustion probes can vent through the top, and the turbulent flow fuel generated in the direction of the obstacles, and with or without the perforations in the top, you see that the one without the perforations where the turbulence, in fact, the turbulent flow is generated just in the direction of the obstacles, you get a very violent explosion and very high pressures because of that.

So you can also compare the three of them, which is just to share with you once more. You see the difference between the three. So, this is the kind of complex processes that we are looking into.

Thank you very much.

So, if I could now just get my next and final slide.

(Slide)

DR. THIBAULT: There are many factors even influencing the course of a gas explosion, and we have to simulate all this. It is the gas concentration, which is important, also the gas clouds, how big is it? If we talk about a center wing tank, is it everywhere? Is it one or two of the base?

There could in fact be ahead of ignition before we ignite, there could be turbulence in the tank or in the geometry. The position of ignition source has to be modeled, as well as what sort of an ignition source do you have. You can in fact generally speaking, you can have the flame jet ignite in the clouds.

The geometry aspects, everything has to be there, the confinement, possibly the vent openings, if you want to do this deliberately, where are they? Are they covered initially? Any equipment which is inside your geometry, what you're looking at, and where they are.

So, all these aspects can differ from situation to situation, and that means that the effects of a gas explosion are scenario-dependent, so they are strongly dependent on all sorts of factors which could differ from accident situation to accident situation. This has to be modeled.

That answers your question, Mr. Crider.

MR. CRIDER: Thank you, Kees.

Now that we have a general overview of the processes, how do we apply those to the center wing tank?

DR. THIBAULT: My next slide then.

(Slide)

DR. THIBAULT: You will see what we need to be able to move this. First of all, we need to be able to model the combustion, and the effect of turbulence on the combustion. It has to be done everywhere. That means both in space and in time.

We should also be able to model quenching, so the turbulence that strong, that if you mix the unburned gas and the burned gas very, very fast, that the flame in fact quenches, just like you. If you have a match and you blow it out, in a way, similar. You also have to be able to determine the effect of temperature and pressure which is changing during an explosion on the combustion.

The fuel dynamics. I don't have to introduce the term any more, but we have to describe the flow in space and in time. We have to describe in terms of generation and the dissipation. We have to describe geometry aspects, in particular in this case, the passageways stringers, the vent stringers, possible ullage partitions. All of that has to be modeled.

My next slide.

(Slide)

DR. THIBAULT: You see what also has to be modeled, but it could be distribution. It doesn't necessarily have to be the same everywhere. If that is the case, we should also be able to mix the gas ahead of the flames, so what is happening is that if you have a cloud which is varying in concentration through the center wing tank, you should be able to describe the mixing of unburned gas from one bay, which may have a different composition into another bay, and then they mix. That may happen ahead of the flame, and that has to be modeled, as well.

Obviously, we have to be able to simulate or describe the effect of ignition location, and some more difficult aspects, like lofting of liquid fuel, interaction of the flame with that fuel, as we saw in the last experiment which was shown by Dr. Shepherd.

And also, something like the interaction of the fluid dynamics which failing partition. So, once the partition is failing, you will get a different flow around that partition that you would have had if it would have been, for instance, at one place all the time, for instance, with the hinge open.

But if it really starts moving, the fluid dynamics has to flow around that flying object, has to be described as well, because it could be important for the explosion. So, those are the processes we should be able to model for this particular problem.

MR. CRIDER: Thank you, Kees.

I would now like to turn the questioning over to Dr. Bower, who has some questions for Dr. Baer.

DR. BOWER: Thank you, Dennis.

Dr. Baer, it was pointed out in Dr. Birky's opening presentation, we're following basically two lines of computational modeling, funding two efforts, and as pointed out in your opening bio, you have been at Sandia National Labs for quite some time doing computer modeling.

I was wondering if you could tell us about some examples of computer modeling you've done at Sandia Labs.

DR. BAER: Okay. I have two examples that I can share with you. Basically, if both examples have to deal with forming teams attacking a problem association with accidents, and how we've implemented modeling to look at these accidents.

The first example comes from studying studies in safety, and can I have the first overhead?

This was some work that was sponsored by the Nuclear Regulatory Commission. It was a study of a hypothetical loss type accident in which hydrogen gas is produced, and there is a possibility of a combustion event that would result.

Sandia's program including emerging analysts and experimentalists and combustion experts from universities, as well as those from our own Combustion Research facility in Livermore. The study was truly aimed at trying to assess the containment integrities and assess any sort of damage that might occur in a containment vessel.

As we saw in Kees' presentation, flow blockages and internal obstacle can have a tremendous effect on flame accelerations, and this was also a part of that study. We use modeling to evaluate not only the over pressures, but also investigation how we can use various schemes to reduce the over pressures, to mitigate the combustion of that.

By and large, all these studies truly did merge, experiments with modeling, and the outgrowth of this is that we became very familiar with things like scaling roles, and truly developed a more engineering-based type analysis.

In the second example that I want to share, this is a little slightly different explosive type study. This is a study that I also participated in, and this was the reinvestigation of the USS Iowa incident. This was done with the U. S. Navy, and we were aimed at trying to determine a probable cause for the explosion that took place in the 16-inch gun aboard the USS Iowa.

As you may well recall, this incident resulted in the tragic life of 47 sailors. What's different to the nuclear reactor events, is that this combustion really deals with gun propellant; however, when a gun propellant burns, it generates a lot of gas, gas generation, and it also induces rapid pressurization.

In fact, an important clue from the event evolved because the projectile that was locked in the gun traveled only part way up the barrel of the gun, and this left a very important clue to determine where ignition first began. We used modeling to assess a probable location of ignition by also doing some comparisons to full scale gun tests.

From that information, then we could determine a pressure time history, which would then tell us the loading onto the projectile, and from the loading, we could determine that ignition first began near the projectile and the propellant train.

Where this took us then was, modeling actually told us then to focus our studies, focus in on how the propellant train interacted with the projectile during loading, and as it turns out, this was the key in discovering that a high speed over ram could trigger the combustion event.

So, in both these cases modeling can be used in a very effective way as a diagnostic tool and accident type analysis.

DR. BOWER: By viewing that graph, those graphs on that chart, we see you have had some good results from using your type of computational modeling. Do you think you could briefly discuss your computational approach?

DR. BAER: Okay.

DR. BOWER: As briefly as possible.

DR. BAER: Yes. Before I describe it, though, I think it's important to point out that once again, the combustion process is an immensely difficult problem to describe and model. You can't forget that.

CHAIRMAN HALL: That equation, I understand.

DR. BAER: At Sandia, we also have one of the largest and most powerful machines available to us in the world, and I've used the machine, and I can tell you that this modeling problem in its entirety, if you describe it in its entirety, it's beyond its capabilities.

CHAIRMAN HALL: Dr. Baer, would you permit me to just interrupt you at this point.

DR. BAER: Absolutely.

CHAIRMAN HALL: And make a comment, and I want to direct this specifically to the families, and of course, also, to the American people.

If it is humanly possible to find out what the ignition source was that caused the center fuel tank on TWA 800 to explode, and how it can be fixed, we are committed to doing that, and we've tried to put together the very best experts in the world that we know, and that's what this panel is all about.

I get many questions from the media, as our other Board members do and our staff does, "What is taking so long?" And I hope again, this panel demonstrates in a very thorough way in which this whole situation is being approached and in which we are trying to get to that conclusion.

I do not know, as you don't know whether we will ever have an answer as to what the ignition source was, but I want all of you all to know that in the summer of '96, once we knew what had happened, I asked Dr. Loeb and Dr. Ellingstad to start assembling, if we could, the best experts in the world to try and solve that problem because I know how much it means to the families. I know how much it means to the American people.

I went out to Sandia and heard a presentation, and Dr. Baer showed me what they had done with the USS Iowa investigation, and which is in some ways similar, and which I think you were trying to find the ignition source there for that explosion; and I don't know where we are in all this, and there are not going to be any conclusions because Dr. Shepherd and all the others that you will hear from today are in the middle of things that probably won't be completed until next year.

But I wanted to be sure that we go through this in as much detail as possible, and that's what we've been doing.

So, please proceed.So

DR. BAER: So, in developing our modeling strategy consistent with the time constraints so that with the impact the quarter scale testing. This really strongly suggested to us that our modeling direction should take the more engineering-based type approach, following a lot of our prior experience and studies that we've done in the past.

To that end, what we chose to do was to seek some approximations that would allow us to solve to model the combustion event, and the first approximation we chose to invoke was, we chose a limit where the motion of the flame is much slower than the speed of sound, and this, as it turns out, greatly simplifies the model description.

Furthermore, we chose an approach where we don't really solve all the details of the flame structure. That in itself is an incredibly complex problem. Overall, what we're aimed at was describing the transient pressures in the various compartments within the tank, because after all, it's the pressure differences that define the forces on the internal structure, and that's really what we aimed at trying to get at.

So, as Paul mentioned here, in formulating a model, we always start with some very basic physical laws, and those laws basically say we're going to conserve maximum/minimum energy, and when we impose the simplifications, the approximations, for example, on momentum, it says that the pressure inside an individual compartment is spatially uniform.

So, we start with these sort of simplified equations of motion.

Then what we do is, in each region where the flame has penetrated, we solve these equations separately for both the burned and unburned portions of the bay. We also allowed gas motion to take place between the compartments. That's real important because that really kind of establishes the turbulence levels.

And this is taken care of by invoking engineering approximations for gas flow by pressure drop correlation. From our prior work, we know that adding heat, including heat losses, is a very important thing to do, particularly in large-scale type commercial events.

So, thermoradiation and heat convection were also included in our analysis.

The combustion has been simplified by treating it as a moving interface, and what that really means is that across this interface, there is a jump in state. It suddenly changes in temperature and density and composition, and that there are some well-known additional conservation laws associated with jump type conditions that we also preserve.

The flame algorithm is really a very dynamic one. It basically relies on a mesh that follows the individual flame list. Flame accelerations is also included and it is included by evaluating the turbulence characteristics of the gas motion, and using the empirical type, flame acceleration type burn loss.

That, in essence, is our model.

DR. BOWER: I notice you mentioned that you did include some approximations; how does that effect your computational time or your time and ability to repeat a computation, et cetera?

DR. BAER: Oh, that's a very important issue because by invoking these simplifications, now we have a model that we can run hundreds and hundreds of times. In fact, we have done that, so it's something that is very quick, very easy, and it's very much adaptable to addressing experimental type comparisons.

DR. BOWER: Do you have any results of the type of modeling you've done related to this investigation in the quarter scale testing that's been done so far that you could share with us?

DR. BAER: Okay. Again, we're only halfway through this study, but the first thing we did was, we chose to model some laboratory type scale experiments because we needed parameters like burn velocities to include in our modeling.

May I have the first overhead.

So, this is a comparison of our modeling to the laboratory scale experiments that were done at CAL Tech. This is one example, and I'm showing the pressure time histories, comparing the experimental data with the model.

The reason why we choose laboratory scale experiment to first model is that it's a very simple geometry to deal with, and what we're really after is some very basic important parameters to the modeling.

Having this information at hand, we then can turn to a geometry that's more representative of the quarter scale test, and now we're looking at essentially, this was test number 11, a quarter scale test, in which there were no partitions.

So, it's just one single compartment, and again, we're using the Jet A simulant hydrogen propane mix, and I compare the over pressure versus time model calculations to the quarter scale test, and the results look quite interesting and intriguing, and encourage us to then go to the next step.

That next step is now to look at adding the effects of the internal structure, the partitions, individual bays. So, what I'm going to show is an animation of what our calculation looks like, but this is the geometry. This is test number 4, and we're going to begin ignition in bay 5, although in the animation, the individual bays are shown there, we do not show the individual passages.

This graphic does show that there is indeed connected flow passages between the bays, and it is this effect that has a very important role in accelerating the flames.

So, can we see the animation?

This is the quarter scale test simulation, .2 seconds in duration, and what we're going to see again is first, the very slow-moving expanding bubble that will begin to fill bay 5, and then once it interacts with the walls, the combustion greatly accelerates as it moves from bay-to-bay.

So, we will repeat this now with just the accelerated part. We will slow down the motion of the turbulent burn part, and really, what this illustrates, as simplified as this modeling is, it's still very complex, and that this is really a cat-and-mouse game where the combustion is moving between compartments and moving through the orifices, and accelerating and sweeping through the whole domain.

So then, we can now turn and look at what calculations versus experiments look like, and here, I show the overlay of the calculations to the experimental data for both the case where combustion began in bay 5, and it traversed through the last bay.

The results look quite interesting. Again, we're only halfway through our investigation. We've got a lot of work yet to do, but this kind of illustrates what our modeling can do.

DR. BOWER: Thank you, Dr. Baer.

At this point, I'll turn the questioning back over to Mr. Crider.

MR. CRIDER: Thank you, Dr. Bower.

I'd like to continue with some questions for Kees. Could you briefly describe what is your model at CMR?

DR. VAN WIN GERDEN: Could I have my first slides, please.

(Slide)

DR. VAN WIN GERDEN: So, we are using a code called FLACS. It's Flame Acceleration Simulate. It is a C of D2, and that is at the moment used quite heavily by industry, gas and oil industry, especially for gas explosion analysis. It has a 17-year of development history behind it, and we have used about 160 men years to develop it. That includes supporting experiments and things like that.

In 1997 this code was used to do consequence studies for several oil and gas-producing facilities in the North Sea, and that's why it has been developed especially for that purpose.

Next slide.

(Slide)

DR. VAN WIN GERDEN: You will see a typical application, so this is an off shore rig and module of an off share rig. It contains some openings. The roof has been taken off so that you can take a look into it, and a lot of things like that. That's why you have this interaction of the flame, the combustion, with turbulence generated at these obstacles.

So, it's a very complicated process which is tried to be simulated here.

So, FLACS has also been used at some incident investigations. We mention three here: West Vanguard. We used a drilling rig which has an explosion in 1985. Piper Alpha, which is a very dramatic explosion where 167 people were killed; and BEEK, which was a land base geometry, and naphta cracker where a vapor cloud explosion occurred.

Just to show what FLACS, how we were involved in the public inquiry of the Piper Alpha investigation, it has some similarities with the present situation. We wanted to know where ignition occurs, and so if I can look at the next slide to see the Piper Alpha accident.

(Slide)

DR. VAN WIN GERDEN: Piper Alpha is a platform, and there was a small minor explosion which occurred in the compressor module. If you look at the next slide, you will see that the compressor module is Module C, and the Module D is the control room.

Explosion in Module C caused the wall between C and D to fail, and as a result of that, they lost power, and because of some peculiar circumstances, they had no power either on the fire pumps, and as a result of that, they got a very major fire after this initial explosion, and they lost complete control, and everybody is given the instruction to go to the living quarters on the module in case of a major event, and especially that living quarters ended up in a very big fire ball, and lost of smoke, and many people lost their lives because of that.

The incident started in Module C, and there was a gas detection system which detected some gas in Module C, and the question was posed to us, whether an explosion of death cloud? If you construct a cloud which occurred in the corner in Module C, the green area, where that could give rise to pressures which could cause this incident, and that was what we found, and we found that the pressure was about .3 bar, could be generated by this explosion, and that will be more than sufficient to have the go between Module C and D to fail.

So, that is why we were involved in the Piper Alpha accident investigation.

MR. CRIDER: What is your basic computational approach with FLACS?

DR. VAN WIN GERDEN: Well, FLACS is a C of D code, and my next slide, it just shows some features. It calculates the compressible turbulent directed flow. It has some miracle solvers. There are flame models in it. It calculates the thermodynamics, all that to describe this complex process of an explosion, interaction with the geometry in which the explosion occurs.

So, what we do is, we put a grid around or on the geometry, and we calculate all parameters which are shown on the next slide.

(Slide)

DR. VAN WIN GERDEN: The parameters which are pressure velocity, so that's the energy which is released. The turbulence throughout the entire computational domain, the fuel fractions are the fuel fractions of how much, how fast, or what is being burned. Also, the mixed fraction which is the mixing of the fuel ahead of the flame because of the expanding combustion flow.

So, then, we show a number of equations, which I just want to show for the sake of, you could almost say, fun. It is just to show you the complexity of the problem, and this is just an approximation of the problem, and we saw these equations in every control volume throughout the entire computation which typically has a numbers of notes, 100,000, or 150,000 in which we solve all these equations.

In my next slide you can see an example of how we treat the cells, are very fine in the geometry where the explosion occurs until we use some coarser cells around it, also, to be able to describe the explosion around the module.

MR. CRIDER: How did you validate FLACS?

DR. VAN WIN GERDEN: So we validate those certain models, and then as Paul Thibault already introduced a way of validation, you first start validating your submodels, which you have in the code. That is something we do all the time. We almost yearly issue a new code which is going through a validation process which is very extensive.

So, we validate all the submodels in the codes, and then we try to validate the whole thing against experiments which have been performed in complex geometries. So, I can just show you an example of a geometry, so if we go over this because of time problems, we can just go to the next slide.

Can we go to the next slide?

(Slide)

DR. VAN WIN GERDEN: Just an example of data that has been used to compare the code. This is a graph showing for many, many experimental rigs, varying from small scale to very large scale, experiments were done, and paid for by the gas and oil industry on a scale of 3,600 cubic meters where they did experiments in the module which could withstand about four bars, which is about 60 psi.

So, you see a very good agreement between the module, the model predictions and the experiments. And I just want to emphasize the fact that not always, experiments tell the truth either, because it is very difficult to perform experiments, as well, and you can have some variations there, as well.

So, I will say that this agreement is quite good.

MR. CRIDER: Do you have some results for us from the center wing tank work?

DR. VAN WIN GERDEN: Yeah, we do. So, two slides further down or something like that. Yes, that is your slide, your left hand, yes.

(Slide)

DR. VAN WIN GERDEN: So, this is an example of pressure time is which were predicted by the code in an experiment where, if you bear with me, I don't have an example of the fuel tank, the slide of the fuel tank. But the front spar is not there. The central - what is it called? - the spanwise beam 3 if failing, and all the others are not failing. An ignition is occurring in Bay 5, which, according to Dr. Bower, is bay left aft.

The ignition occurred in that bay, and then you see the pressure time is reaching each bay and you see some high pressures. Those are in the bays where the partitions did not fail, whereas, the ones which are much lower, are in fact in the bay 1, and in the bay zero. The wall, the partition between bay 1 and bay zero failed, and there was no wall, on the other hand, of bay zero. So, the front spar was not there.

This is the kind of predicted pressure time that you get.

MR. CRIDER: Okay.

DR. VAN WIN GERDEN: And I also videoed that which shows some assimilation, and the idea is, first of all, to compare with experiments.

If you could just start the video.

Could you hold it here? Thank you.

So, this is the way you can see the combustion propagating in the center wing tank. The left one will show the development of the flame, whereas, the right one will show the development of the pressure, and that the development of the pressure is showing changing of color.

If you have blue, it is low pressure. If you go to the red one, you get high pressure. Now, I just want to say that this first one is a simulation where the walls are in fact failing. You won't see the wall flying away because we cannot describe that, but we can describe the failing of the wall by some analytical method where the walls just stay in place, but they open with varying velocity at that location.

So, on the left side, you will see the flame developing, and on the right side, you will see the pressure developing. First, it was done rather quick, so remember, the walls are failing in this particular one. Ignition occurs in bay 5, and you see how the flame develops.

You may also see some jets in this particular one bay, a 6. You see the pressure there reflecting on the walls, giving some red colors, and also propagating back into the tank. Just show it show once more. So, if you pay attention to the right one, you can see that there is some pressure waves in, I think, it's bay 2, which occurred on the top side, and then reflected on the bottom side. You get some red colors there which indicate strong reflections.

This is a typical result. We assimilated several other situations, as well. The next one is in fact the one which was also shown by Dr. Baer. We have two more which showed weak partitions where we used mixtures, which are not the same as using the experiments, but they are leaner, trying to reconstructed the scenario which could have led to the same damage as observed in the accident. So, that's what we are trying all the time.

Now, at this moment, we use most of the effort into trying to explain with the model what happened in reality, so that we vary the concentration, that we vary the ignition location.

Thanks.

MR. CRIDER: Okay, Kees. There is one more question, I think, for you, in this series. Again, we've had good communication between the team members on this, and how does it compare, your work, compare with the experimental work, and again, comparing with Mel's results?

DR. VAN WIN GERDEN: We made the comparison forthwith. It is test number 4. If we can have the overhead.

You see here the pressure time is 3 in one of the bays. I'm not sure which one it is. It's shown on the overhead at the moment on the left side. It's in bay 1. That is the bay between spanwise beam 3 and spanwise beam 2.

There, you see the three different curves. You see the experiment, which is the one which has the vibrations on the top. You see the FLACS one, which is blue, and the Sandia one, which is red. And you see that there is also not only in rise time, but also in fact, a moment of arrival of the peak pressure, very good agreement between both the codes and the experiment.

And you see that this is in fact the case for other bays, we well. We could, of course, show them all, but just another example showing how the comparison is. It's promising.

DR. BOWER: All right. There is one more item we have. Do you have a comparison of the approaches, that is, a tabular, something to compare the approaches?

DR. VAN WIN GERDEN: Yes. We have a table comparing the two codes where you can see what the differences between the codes are, and I think I should emphasize then on the differences, because there are also some similarities.

But I think the differences are in the flue dynamics. There were some differences in the heat loss. The heat loss may be very important, especially for slower events. During the combustion phase, the flame will lose energy to the environment. That is modeled, as well, in both codes.

But then in the Sandia code it is mainly radiation, drizzles of convection, as in the FLACS code, it is mainly convection. In fact, we also see that the Sandia code at the moment at least, could not handle failing partitions which FLACS up to a certain extent and handle.

Both codes could not handle interaction with liquid, so lofting of liquid cannot be handled. Neither can we handle the interaction of a panel which is flying through the center wing tank after it fails, and the interaction of that panel with the flow.

There is also a difference in the gridding. In FLACS we have a cetacean grid which means it's a square kind of grid, just blocks everywhere, cells; but we do not have local grids refinement as the Sandia code has.

MR. CRIDER: All right. Thank you, Kees.

I'd like to turn the questioning over to Dr. Bower, who has a couple of final questions for this modeling subsection.

DR. BOWER: I guess I'll direct this right to Dr. Thibault. Keeping in mind that our original objective in all this modeling and testing program is to help find an ignition location. We have seen some examples of how modeling is done to match the quarter scale experiment so far.

Could you just give a brief comment on what type of calculations you see on-going in the future to help us perform our original objective in defining the ignition location?

DR. THIBAULT: What we have is an analysis of an accident. We are trying to figure out where the ignition occurred. There are few things that we don't know, and there are few things that we have some information on. What we don know is the ignition location. That's our job to find out.

We don't know exactly the concentration and concentration distribution in the tank, but thanks to those very important flight test data, we have some information on the range of concentration, and concentration distributions we might expect, and that's very important. So, we have that information. We have some information - and this is a difficult part - we have some information on the damages to the tank.

As mentioned, some of the partitions failed, and some didn't. So, what we have for us is that we have a limited knowledge of the damages. Basically, just what I said, some partitions fail and some dent, and we know which ones those are.

We have some idea of the fuel concentration distribution, and that's flight test data. So, what we need to do is to vary the ignition location, vary the fuel concentration distribution, and figure out those scenarios - the scenario - or those scenarios that are consistent with the damages that we observed. That basically involves a parametric analysis to figure out which scenarios are consistent with those damages.

DR. BOWER: Do you anticipate that any studies will lead to a unique scenario that could have caused these damages, one particular unique solution?

DR. THIBAULT: Well, we have two things that we have to understand here. First of all, as Dr. Baer said, this is a very complicated process, and we have to do the best job we can with our models, with validation and with experiments. Where we are right now, we are in the validation phase, so that's where we are in the process. So, we haven't really started answering that question.

But the other thing that we have to understand is that even assuming that our models were to be perfect, absolutely perfect, what we have is that we have some panels failed, and some panels didn't fail; that's the information we have. And we have to figure out those scenarios that are consistent with that.

It could be that we find no scenarios. It could be that we find a narrow regime of scenarios, which would be very helpful in locating the ignition, or we may find out that there are quite a few of scenarios that could lead to that result, even with the most perfect models.

So, where we are in our investigation, that's all I can really tell you about what we're likely to find out.

DR. BOWER: Thank you for that very candid answer, Dr. Thibault.

I am going to turn things back over to Dr. Birky.

DR. BIRKY: Yes. In the light of the hour, I had a lot of questions to ask Dr. Shepherd, but we won't do those now, but what I would like to do is, summarize what we know today, the good news and perhaps the bad news, and we've heard that we haven't located the ignition source.

But I think we do know the following:

(1), we know that the flammability, the temperature in that tank was above the flammability limit in flight; (2) we know how to reduce that temperature significantly; (3) we know that the ignition energy goes up rather significantly as the temperature of that fuel goes down; (4) we know that our best methods to reduce that temperature beyond the addition of fuel.

I think we heard a suggestion today from Boeing about radiation shield and a little bit of ventilation.

All of those things would contribute to reduction or increase of the temperature.

CHAIRMAN HALL: Yes. Let's get a comment and then we will move to break here, because I'd like to finish this panel today, if we can, and we haven't had the opportunity for the party questions, or the Board of Inquiry, so it looks like we're going to be here for a while, so we will get a comment from Dr. Shepherd and then take a nice break and come back and finish our work.

DR. SHEPHERD: The only comment I'd like to make at this time is that I believe that I'd like to second your earlier comments, Mr. Chairman, and that this group has worked over the last six months together to try to integrate our findings in the laboratory and our field testing, quarter scale experiment and the modeling towards this goal of identifying the ignition source.

We are going to continue to work at that, and I hope to be able to report back to you in a much more positive way.

Thanks.

CHAIRMAN HALL: Anything else, Dr. Birky?

DR. BIRKY: No, sir. We can take a break.

CHAIRMAN HALL: Well, let me say, Dr. Shepherd, first, how much -- and we got the party question, and this is certainly no summary because we've got plenty; but I do want you all to know how much I appreciate all of you gentlemen and the various organizations that we have reached out and tried to assemble all the work that you have done.

I certainly understand again that there is no guarantee that we're going to have an answer, but I do want to stress again, I want to be sure that the American people and those who lost loved ones on the flight, know that we're doing everything we can.

I appreciate very much what I heard today from FAA and Boeing, that they are moving ahead now to not only look to eliminating the ignition sources, but looking also at ways to reduce the vapors; and I think that's a very positive report, and I appreciate that very, very much.

So, let's take a break until 6:30.

DR. BIRKY: Mr. Chairman?

CHAIRMAN HALL: Yes.

DR. BIRKY: May I just interrupt one moment, please? Can I say to this panel, the contractors we have on this program, in my 35-year professional career, I don't think I have ever worked with a better group, and it's a very impressive group, and I appreciate their activities and their work tremendously.

CHAIRMAN HALL: Well, I asked you all to put the best together. If this isn't the best, we will find out if there are any more we need to add; but I appreciate that, Merritt. That was a nice comment.

All right. Unless the parties have objection, I'd like to get this panel finished today; otherwise, we may be doing this Friday night, and I assume everybody would rather do it tonight.

I'm hearing, seeing nods of agreement at all the tables except Honeywell.

Honeywell is now nodding.

But let's take a nice break until 6:30, and then we will come back and continue the session at that time.

(Whereupon, a brief recess was taken.)

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

We have just heard from our expert panel in the area of flammability, and before we move to the Party table, Dr. Birky tells me he has a couple of brief questions he is going to address.

DR. BIRKY: Really, I think just one.

I wanted Dr. Shepherd to show his information on ignition function as a function of temperature. That study, I think, is very informative in terms of reducing the risk of ignition in the center wing tank.

Dr. Shepherd, could you do that?

Presentation By

DR. JOSEPH SHEPHERD

DR. SHEPHERD: Yes. I believe that this is one of the most important results of our laboratory testing, we had some notion about flammability limits and BEEK pressures from the previous work that had been done, although there was a great deal of uncertainty about the application to this particular accident; but about this particular area, ignition energy, we had almost no information, and what is most striking to me is that when you look at this picture, you see - and it's important to note for everyone who is not familiar with working for logarithmic curves - that the axis on ignition energy expressed a range of 100,000 between 55 or 60 degrees Celsius, that is, 140 Fahrenheit, which is the type of temperature that was measured in the fly test, and a temperature which would correspond to a moderate day, or even a warm day, 86-to-90 degrees Fahrenheit.

This enormous range in ignition energies, I believe, indicates that there is a significant gain that could be made in safety if the temperature of the fuel can be reduced.

DR. BIRKY: Thank you, Dr. Shepherd. That's all the questions I have.

CHAIRMAN HALL: Very well. Thank you, Dr. Birky, and thank you, Panel.

We will now move to the Commercial Airplane Group - Mr. Rodrigues.

MR. RODRIGUES: Boeing has no questions, Mr. Chairman. Thank you.

CHAIRMAN HALL: The Airlines Pilots Association Captain?

CAPT. REKART: Yes, sir.

I guess, Dr. Shepherd, there has been some discussion about the fuel weathering and its affect on flammability. Have there been any efforts to characterize the weathering as a function of pressure and temperature, or is it strictly a function of time?

DR. SHEPHERD: Let me answer that by discussion in a little bit more detail the weathering issue. I had hoped that we would have had time for Dr. Sagebiel to spend a little more time on that because he looked at that in some detail.

The data were expressed in terms of time when he discussed, but the primary consideration we need to make is this: What is weathering? Weathering happens because when the fuel gets hot, it vaporizes, and then when you climb after you take off, you vent that air and the fuel in it out of the tank as the pressures goes down.

So, what you're doing is, you have a little pump there. You vaporize some of that fuel, and then you suck that fuel out of the tank. Now, if you leave the same fuel in the tank, and you do that repeatedly, as they did in the flight test, every time you heat up that fuel tank and climb up in that airplane, you're pumping out that vapor, and when you're doing that, you're withdrawing, as Jim Woodrow showed, the lighter components.

So, the key parameters are really not time, but the number of times that you pump on that liquid, that is, how may times do you climb and descend?

Now, in the case of the fuel from Athens and back, that was exactly once; right? And not only was it once, but at the point when the airplane was climbing, in fact, there was a good deal more fuel in there than the 50 gallons that was tested in the Evergreen flight test, and we don't know what the temperature was of that fuel at the time it left Athens. I don't have any details on that. Maybe there are some. Dr. Birky is shaking his head, "No."

So, I think in fact, the weathering issue is now very significant for this accident.

CHAIRMAN HALL: Does Dr. Sagebiel want to add anything to that? Dr. Shepherd says we cut you short. We don't want to cut anybody short.

DR. SAGEBIEL: Yes, sir. I could just re-emphasize what Dr. Shepherd just showed, and I don't know if we're going to risk doing this, but we might actually switch the video plus here, and try and get -- if we can speak to this momentarily.

There is a figure I would like to show you - there it is - that describes the flight sequence. Okay, it's still on there; that describes exactly what Dr. Shepherd stated, and that is, that the fuel was added down here at times zero on this figure, and the aircraft, the test aircraft, that is, in the flight test program, went through these excursions to 19,000 feet.

Okay. My apologies. I must have hit something there; went to an excursion to 19,000 feet, went to another excursion all the way to 35,000 feet, another excursion to approximately 17,500 feet, another excursion to 35,000 feet; and then a vapor sample was taken here during climb at nearly 60 hours of flight operations, and that vapor sample, we were still able to reach a fuel air mass ratio that was in the flammable range.

This is many more excursions up and down, which is what weathers the fuel. The amount of time spent at any one particular altitude, say, up here, is not nearly as relevant to the weathering as is the fact of the going up and down. The fact of going up and down has a much greater impact on the weathering than does the actual time spent at any particular altitude.

And I have some additional data that describes the tank venting.

Dr. Birky, would you like me to describe the venting tank data?

CHAIRMAN HALL: Yes. Proceed. Now, the taxpayers paid for a lot of all this, so we want to hear it all.

DR. SAGEBIEL: Very well. In the analysis of the samples that I conducted, I did actual several analyses, and to get as much information as these samples, as I said, these were the first, and as far as I'm aware, the only time we have ever actually sampled the tank --

CHAIRMAN HALL: You don't have a picture of that, do you?

DR. SAGEBIEL: Yes, I do.

CHAIRMAN HALL: Dr. Bower took me over the plane where the bottles were. I think that would be interesting to show if you had a picture of how you did that.

DR. SAGEBIEL: Sure, I will be happy to. In fact, I will do that right now.

CHAIRMAN HALL: When you talk about taking vapor samples out, it's hard for someone to maybe visualize that.

DR. SAGEBIEL: The samples were collected in the pre-evacuated one liter stainless steel cylinders, what I refer to in my business as cans or canisters. These are commonly used in air sampling to collect an air sample. These are a very convenient device for a number of reasons. It can be made very, very clean. It can be checked for cleanliness, and then evacuated so that when it's exposed to air by opening a valve, it draws an air sample into the cylinder.

The cylinders are also quite durable, and they can be shipped by any number of means, including the U. S. Postal Service, Fedex, UPS, you name it, to another location, and they maintain their integrity. They maintain the integrity of the sample.

In this case, the canisters were connected to the center wing tank by a manifold in a small one-eighth inch stainless steel sampling line, and that line of manifold were purged immediately prior to each sample, so that we were sampling a representative sample.

Just so you get an idea of positionally where this was in the aircraft, this is a top view now with forward being at the top of this figure, you're looking down on the center wing tank with the stained conventional beams being drawn in here.

The sample was collected in the space between spanwise beam 3 and spanwise beam number 2 approximately 12 inches away from spanwise beam number 3, and approximately 35 inches up from the floor level of the tank. The line traversed across the Drive A to the light on the aircraft, and then into the forward cargo bay.

Sampler then was attached there, and this is what it looks like from the top down looking at it. These are the one liter bottles. This box was designed to be completely sealed. There would be a top lid on it during operations, and that's just to prevent any possibility of any leaks, allowing fuel vapors into parts of the aircraft. They are obviously not desirable.

The canisters have their own shut-off valves here with the small mural knobs, and then were connected to this manifold to a second shut-off valve that was operated through the box so that the stems of those valves go through the box so they could be operated from the outside.

In the actual aircraft it was something like this. It's not quite as good a picture. You can see here, this is the forward spar where the arrow is sitting, the thud spar where the arrow is sitting back here. This is one of the water bottles that gets discussed and was discussed as they were simulated in the quarter scale tests.

And this is the actual manifold enclosure as it was ready for flight with a strap down over the top of it, and ready to go flying. So, that's the actual locations of the physical operation.

If I can jump back then momentarily here. One of the findings that we had in the samples was something called an HCSC, and not to get too heavy with acronyms, it's a hydrochlorofluorocarbon. You may only be familiar with chlorofluorocarbons, CFC's which used to be used as the common refrigerants. CFC 12 is what is in those common air-conditioning and refrigeration type applications.

These had been replaced because they are ozone depleting chemicals. That's a whole another discussion, and they have been replaced with these hydrochlorofluorocarbons which are chemicals that are much less destructive distress.

In any case, a can of material containing the hydrochlorofluorocarbon number 141B was used to test the thermocouples. This was sprayed onto the thermocopules, as this was described to me by Dr. Bower, and used. That would then cool that thermocouple, and that gave an indication on the data system and allowed the data system operator to confirm that the thermocouple was in fact connected and operated.

So, this is thermocouple testing that took place in the tank. As a result, there was a residue of this chemical in the tank, a very small amount, mind you, but in my analytical capabilities, this type of chemical can be detected very, very easily. It is among the most easy to detect chemicals that are commonly found in air.

HCFC 141B is stable certainly under the conditions in that tank, which is to say, no sunlight, no further chemical activity. It is inert, for the most part, not going to react like the fuel molecules, and there is no source of it in the tank which contrasts with the fuel, which of course, had a liquid source in the tank during the flight test.

Unless the behavior of this chemical is going to be subtlety, yet very importantly different from the fuel, whereas, as the fuel weathered during the excursions up and down in altitude, this compound is not going to weather because it's a single compound, and it is going to leave the tank, based on, as we described, these excursions up and down in altitude.

Just to show you why I went after this, this is a chromatogram of one channel, what we call the ECD, or electron caption detection, part of my analytical system, and when I saw this, I was expecting only to see oxygen because oxygen responds on here, and when I saw this other component out here, and you can see that that's essentially a rise in this signal here, indicates a component eluding from the system, this was essentially the only other rise. This is some noise caught generated by the fuel that's being analyzed at the same time.

So, obviously, I found this to be very interesting from a scientific standpoint, and it turned out to be interesting from the standpoint of flight tests. When we consider this in relative concentration amounts, that is, the HCFC to air ratio, going up in altitudes, since both the HCFC in the air or venting at exactly the same rate, they are both pure gases under this standpoint, there will not be a change in concentration, and that is approximately what we measured within an error of about 4.8 percent; that those three samples were exactly the same for our purposes.

On the second flight, similarly, those three samples were the same, but much lower; and on the third vapor sampling flight on the 16th, those concentrations were again much lower, yet again, precision even better than it was earlier in the flight test.

This indicates that we had a good sample collection. This indicates that the sample collection was not in error because had this ratio changed, the HCFC to the air ratio changed, we would have indicated a problem.

We tried to use this then to understand tank venting, and in order to that, we made a calculation based on the expected concentration from the first flight test where there was a vapor sample, through the rest of the program, based on the excursions to altitude, making estimates based on the pressure that the tank was exposed to at the maximum altitude of any given flight and to the temperature of the air at that point because as the plane begins to descend, it draws in slightly cooler air than the actual tank.

As I said, this is very strongly tied to the weathering of fuel. The results of those calculations were very good where we were able to show here -- now again, this is a quarter of magnitude scale because the concentration dropped off quite rapidly, but there are three triangles up here indicating the three observed values from the first flight test; three triangles again here, and the line showing how we calculated where this point should be, and again, how we calculated where this point should be.

And what I want to say here is, the ability to calculate the concentration show the tank venting, is in fact very well understood, based on these excursions in pressure, and that is very critically tied to the issue of weathering, and the number of trips taking up to altitude and down is the critical parameter.

Time was essentially not a variable in the calculations I did for this here.

CHAIRMAN HALL: Thank you.

Captain?

CAPT. REKART: The only other question I had, sir, was, Dr. Shepherd, and I believe, Dr. Baer, referred to additional work to be done, and I was just wondering if there was a time table for that, and how much additional work you have planned?

CHAIRMAN HALL: That's a dangerous question to ask people who are experts. I'm interested in what the time frame is.

CAPT. REKART: Well, we are, too, since it determine our workload to a certain degree.

CHAIRMAN HALL: Dr. Shepherd, I hope you don't mind us putting you on the spot here, because I didn't do it; Alpha did.

DR. SHEPHERD: That's what I'm paid to do, to be put on the spot.

So, what I would like to do, in answering that, I would like to indicate first of all, kind of summarize where we are at to give you a feeling of where we need to go to, to give you a notion of the amount of work that's involved. I'm hoping that in that process, you will get some understanding of what we had in mind.

First of all, the quarter scale program has really only been underway, the actual experimentation portion of that, since the middle of October with a great number of breaks, or as we used to say in Upstate New York, snow days. Since we're doing it in Denver, we've had a lot of unusual weather this year.

Despite that, we had been able to do about 27 tests, and we have so much data now, that we're completely inundated with that. We need to analyze all of that data from those 27 experiments, plus the 3 more that we plan to do.

Where we are at in this is, -- this is not going to work because I'm going to have to flip this around -- What we have learned so far is the rapidity with which the combustion occurred once we burn the ignition, and that the pressure and the time increases very rapidly after an initial delay.

It's quite striking to see the entire pressure traces. We didn't show those in those comparisons, and what I would like to do is, go back here a little bit and pick up some material that I didn't have time to show earlier.

This is one of those results from an experiment. This was the first test that we saw in the video. This was also a test that we saw some comparisons with that Mel and Kees showed, and you see here six pressure traces from six transtesters.

Now, what you would like to do is look at this data, and look at this data for experiments that have been carried out with ignition and all these different possible locations, understand what this data tells you about pressure differences across the partitions, which is what makes them move, and then understanding what makes them move, come to some prediction of, did they move in a way that we believe they moved in the accident, as determined by the sequencing group?

And in that way, attempt to narrow down an ignition location. Now, one of the difficulties here is shown by this white bar. That shows you where the failure pressure is, and you can see that, and so the failure would occur very early in this process.

So, that means that these results are not terribly sensitive to the ignition location. But we do believe that there is a sense to try to understand that, that we have got to digest all of this data, and then one of the most important parts is, we need to understand how this quarter scale experiment with all of its deficiencies relates to the full scale tank, because this is not the actual tank; right?

And that's going to require a great deal of work on the part of the modelers, and at this point, I think Mel and Kees can say something as to the work that they're going to need to do on this part of it.

DR. BAER: Well, certainly, we're still in a validation stage in our modeling. We're not close yet to the predictive at all. We've got a lot of comparisons yet to do with the existing tests that have been done, as well as the projected additional tests that are going to be done here shortly.

DR. VAN WIN GERDEN: Perhaps I can add to that that we also should look into how important these two model the way the failure of the partitions occurs, how important it is to model that accurately.

The experiments we assimilated with our codes show that those do not agree at all, in fact, so that the way the partitions fail in the experiments, and possibly also in reality, is completely different from what we see in our model predictions. So, it may be necessary, if you want to scale up to a large scale, that we describe that much better, and it's something we have to look into in more detail by analyzing the data in more detail.

CAPT. REKART: Thank you, Gentlemen.

Airline Pilots has no further questions, Mr. Chairman.

CHAIRMAN HALL: You hear a date, did you, Captain?

CAPT. REKART: No, I didn't.

CHAIRMAN HALL: I was afraid of that.

Honeywell, Inc.?

MR. THOMAS: Thank you, Mr. Chairman.

No, it's not there.

CHAIRMAN HALL: Are we having a microphone problem? You have no questions? All right. No questions from Honeywell.

Crane Company Hydro-Aire.

MR. BOUSHIE: Thank you, Mr. Chairman. Crane Hydro-Aire has no questions at this time.

CHAIRMAN HALL: The International Association of Machinists and Aerospace Workers?

MR. LIDDELL: Thank you, Mr. Chairman. IAM has no questions at this time.

CHAIRMAN HALL: And Trans World Airlines, Inc.?

MR. YOUNG: Thank you, Mr. Chairman. TWA has no questions at this time.

CHAIRMAN HALL: Thank you, Captain.

Federal Aviation Administration?

MR. STREETER: My apologies, Mr. Chairman. We do have some questions here.

CHAIRMAN HALL: Well, no problem.

MR. STREETER: Dr. Sagebiel first: In your first presentations, sir, you showed a graph that had three flights overlaid, and the flights were numbered, and I wanted to make sure that -- I wasn't familiar with the flight numbering.

Was one of those the flight that carried the additional 12,000 pounds of fuel?

DR. SAGEBIEL: No, sir. I'm sorry, we did not sample the flight that carried the additional fuel.

MR. STREETER: Okay. In that case, I would like to refer then over to Dr. Bower, and find out, sir, do we know whether the plane that carried the additional 12,000 pounds of fuel, did it get into the explosive range, or can we tell that?

DR. BOWER: Well, we do have the temperature information.

MR. STREETER: Okay. Based on the temperature information, did it get into the range that we presumed to be explosive?

DR. BOWER: Well, I can display the temperature information and perhaps our explosive experts can have some comment on it.

MR. STREETER: Okay, that would help.

(Pause)

CHAIRMAN HALL: Do you have another question -- oh, there we go.

MR. STREETER: Now, which line is the additional 12,000 pounds?

DR. BOWER: This is the flight with additional 12,000 pounds.

MR. STREETER: the red?

DR. BOWER: The red is the temperature --

MR. STREETER: Oh, I see.

DR. BOWER: -- that is immersed in fuel. These temperatures down here are in the yellow in the center and upper measurement locations, and the TWA 800 emulation flight -- I'm sorry -- the TWA 800 explosion altitude is represented right here (indicating).

So, we're looking at temperatures when it was in the ground and in taxi of approximately 90 degrees in this bay, and reduced to about 86 degrees at the event altitude.

MR. STREETER: And that's at the upper probe, is that correct, or the upper sensor?

DR. BOWER: Yes, upper and middle sensor, and they're approximately equal.

MR. STREETER: And then the lower sensor stays what - just below?

DR. BOWER: The lowest sensor, which is immersed in the fuel, stays approximately 96, 98.

MR. STREETER: Okay, stays under 100 degrees.

DR. BOWER: That's correct.

MR. STREETER: And I'm not sure, if I can refer back to the Board then, or the Panel up there, since we did discuss various temperatures today, and you stressed that not all of these numbers were hard numbers, does that appear to have placed in the range of an explosive vapor or not?

DR. SHEPHERD: To address that question, I would like to once again return to this slide which shows ignition energy as a function of temperature. We're talking about a temperature of 100 degrees Fahrenheit, which puts us right in this region here, and we see in this region, we're talking about ignition energies which are on the order of about 10 jewels.

I think the important consideration here is that that ignition energy, although you would classify this picture as flammable if you had a 10 jewel source in there, that mixture is in fact 10,000 times less flammable than it would be if we had no fuel in there at all, in which case, the temperatures would be 140 degrees, and the ignition energy would be 1 millijewel.

MR. STREETER: Okay. And this particular chart here is based on which altitude?

DR. SHEPHERD: This is based on the altitude of 14,000 feet.

MR. STREETER: Okay. Thank you.

DR. BOWER: Dr. Shepherd, also, the temperature in the ullage is actually 86 degrees, not 100.

DR. SHEPHERD: That's right, and so that's a complicating factor because the temperature of the fuel, and the temperature of the ullage are not the same. The concentration that you get of the vapor will be actually according to some temperature that's intermediate to those two.

That probably required detailed consideration of the heat and mass transfer in the tank, but you would actually fall somewhat lower than that 100 degrees; I was just being pessimistic on that side, Dan.

MR. STREETER: But the 86 that you're showing here then is the liquid temperature?

DR. SHEPHERD: In our experiments, the temperature is uniform. We had common temperature of the liquid and the vapor. In the tank, of course, it's not.

MR. STREETER: Understood. Thank you, sir.

Dr. Bower, on the flight test and specifically on the test where the additional 12,000 pounds was carried, it is my understanding that we had two AC packs running; is that correct?

DR. BOWER: That's correct.

MR. STREETER: Were they the same ones as on the accident flight?

DR. BOWER: I don't believe they were. I believe we ran packs. I'll have to check my docket on that.

MR. STREETER: Do you recall, aside from numbers, do you recall if they would have been the two packs down on the left side of the aircraft, or were they side-to-side.

DR. BOWER: Side-to-side.

MR. STREETER: Side-to-side. Okay, thank you, sir.

DR. BOWER: In fact, I believe it was the pack on the right, and the rear pack on the left, if I'm not mistaken.

MR. STREETER: Okay. The right and the left rear?

DR. BOWER: Correct; as opposed to TWA with 1 and 3, which were the two/four packs.

MR. STREETER: Again, on both the flight with the additional 12,000 pounds, and on the TWA emulation flight, was there any difference in the fuel that was added to the center wing tank?

DR. BOWER: In the TWA 800 emulation flight, there was no fuel added to the center wing tanks since the fuel had been in there since the previous flights. For the flight with the 12,000 pounds of fuel added, the fuel, as was measured on the truck when it was put in, was still fairly warm, and it was actually up around 86 degrees.

MR. STREETER: Okay. About 86 on the flight where we added the fuel?

DR. BOWER: The flight where we added the fuel, and that's an approximate number. I'm trying to remember that off the top of my head.

MR. STREETER: Okay.

DR. BOWER: It was in that range.

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

Again, to the flight with the additional 12,000 pounds, that one was done with, as I recall, with a 90-minute ground run; is that correct?

DR. BOWER: That's correct.

MR. STREETER: As opposed to the three hours on the emulation flight?

DR. BOWER: That's correct.

MR. STREETER: Okay. Have you done any analysis as to what the effect would be had that same flight been performed with a three-hour ground run?

DR. BOWER: We had a previous test where we had 6,000 pounds of fuel in the tank and ran the packs for a longer time; however, as I mentioned, due to larger amounts of data, we're still in the process of downloading and analyzing that data.

MR. STREETER: Okay.

DR. BOWER: We do have data that is available.

MR. STREETER: Is that an answer that we

expect to be worked up through analysis, the effect of three hours of ground time on that 12,000 pounds of fuel?

DR. BOWER: I'm not sure I'm following you.

MR. STREETER: Well, I guess --

DR. LOEB: The answer to that is, yes. Obviously, we're going to be looking at all those data, analyzing all those data and making them available.

MR. STREETER: That's fine. Thank you.

And now for this, I'm not sure if this would be Dr. Bower or Dr. Birky:

When the additional wiring was added to the airplane prior to the testing, I believe there was a -- well, I shouldn't say "I believe" -- was there a failure modes and effect analysis done on that installation?

DR. BIRKY: The Boeing staff did that work, and, yes, there was.

MR. STREETER: Okay. Did the findings of that analysis require any changes in operational procedures that would have made anything significantly different from TWA's normal procedures?

DR. BIRKY: Not that I'm aware of.

DR. BOWER: None that I'm aware of either.

MR. STREETER: Okay. Thank you.

Dr. Shepherd, please, on your quarter scale tank testing, you gave what I thought was a good explanation of how you worked some of the weakened panels in there, but the way I see the tank set up, I want to make sure I have it right. It doesn't simulate any of the bulging of the upper and lower surfaces; is that correct?

DR. SHEPHERD: The panels are held in by a set of screws, seven on the top, and seven on the bottom. I don't have a detail of the panel here that I can show you. What I can show you is what those panels looked like when they come out of that tank, and I'd like to do that right now.

Now, if you look closely at this, and I will help you out by putting a pointer on here, there are two panels that are wrapped around the post that we used to catch the panels so that they wouldn't break of some pressure gauges we had further on.

Those two panels are, of course, the front bar and spanwise beam 3. This is a test that was done without any liquid jet fuel in the bottom of the tank, so we could see what was happening with the panels, and that would be the spanwise beam 2. That would be the mid spar, and that's spanwise 1.

Now, you can see these come out in all

different shapes and different amounts of deformation, which are due to the way in which they are torn out of the tank, and some of them are bent and twisted and are quite marked, and others appear to be relatively intact.

So, there is in fact bulging if you look at some of the high speed of movies that we have where we look through the sides, we can see through the sides here, the sides of the tank I'm pointing to with my little pointer, and when we actually see the panels begin to fail, you can see them bulge.

MR. STREETER: Now, is that bulging on the failed panels, or on the upper and lower --

DR. SHEPHERD: The way we constructed this, we had to make some design choices in order to be able to re-use this facility, and so the top, this portion, and the bottom and the back are constructed on a three-quarter inch steel, which in addition, you can see there is about a 10-inch structure eye beam, and then mounted across, running across are more structural eye beams.

So, that part of the structure is in fact designed to withstand the 100 psi over-pressure. So, in that way, it does not model the response of the actual time. That's one of the many ways it fails to model. This was not designed to be a structural model, by any means.

The reason why we put the failing panels in there was really to look at how the panel failure would affect the combustion, not to see the panel failure itself.

MR. STREETER: All right. Understood, sir.

Given the fact that the one element of the sequencing groups work appears to be that there was some - I think it's safe to say - significant bulging of the upper and lower surfaces in the tank for the entire panel, because I don't know which one would be appropriate, is that something that's possible to model in the future work?

DR. SHEPHERD: First of all, it's something that we obviously are not modeling right now. In principle, there are things that are difficult. Some of the combustion aspects are difficult. Modeling the structural response, if we really have a good characterization of the real system, in other words, that we know exactly what was there, in principle, that is not usually difficult.

It's a matter of taking a structural response code of which anybody in the airline industry here are familiar with, so I won't bother explaining that; and coupling it to the CFD codes, it is more a matter of the labor of doing that and making sure that the algorithms are correct.

So, in principle, yes, it is possible to do.

MR. STREETER: Do you know yet whether there are plans to do that?

DR. LOEB: Let me try to deal with this, if I can. The answer is, yes, we're going to do everything we can to couple eventually the structural modeling as well. Ultimately, we may in fact carry out full-scale testing on one or two tanks to see and to try to validate against the structural modeling, as well.

We're not there yet. We have a long way to go to complete these tests, but there was no attempt - and I think it's important to understand what Dr. Shepherd - there was no attempt to replicate structurally. That's for the future.

MR. STREETER: Okay. Thank you, Dr. Loeb, and that also answered my last question which was about full-scale testing.

That's all I have, sir.

CHAIRMAN HALL: Thank you very much.

Do any of the parties have any questions that you have not had an opportunity to ask this particular panel?

(No response)

CHAIRMAN HALL: If not, does the Technical Panel have any additional questions?

DR. BIRKY: Well, I don't have any additional questions, but I would like to make one other comment, if I may, Mr. Chairman.

We relied fairly heavily on Boeing for these flight tests and the work they did, they get that aircraft instrument, and I would like to recognize them for that effort.

CHAIRMAN HALL: Well, the Chairman also appreciates that. I went up to New York. I got on the Evergreen plane and I saw all the work that had gone into doing the instrumentation, and, of course, I noted the comment about the failure analysis, because I had to ask the question, well, if you're re-simulating TWA Flight 800, how are you going to be sure that you don't have the same result?

So, I thank Boeing for your assistance on that. Obviously, you all provided a whole lot of very important technical assistance in that test.

MR. SWEEDLER: Thank you, Mr. Chairman.

CHAIRMAN HALL: I guess we will move into the Board of Inquiry.

Mr. Sweedler?

MR. SWEEDLER: I have no questions, Mr. Chairman.

CHAIRMAN HALL: Dr. Ellingstad?

MR. ELLINGSTAD: Just one question for, I believe, Dr. Bower and perhaps Dr. Shepherd:

I understand with respect to the flight test that this is a relatively unique data collection activity that was conducted. Dr. Sagebiel mentioned that he was not aware of previous attempts to do any vapor sampling.

Are yo aware of any other flight tests that have gathered these kinds of data?

DR. BOWER: I'm aware of only the one previous test done by Boeing in the Majuave Desert in August '96, I believe. Aside from that, I know of none other.

MR. ELLINGSTAD: Are there other similar kinds of measurements that you see a need to do to more fully understand the environment in the center wing tank?

DR. BOWER: Yes, I believe so. We got a lot of interesting data in the flight test which often happens in an experimental program. It just opens up the door for more questions.

I saw a lot of warm temperatures underneath that center wing tank in the air-conditioning pack bay. You see a lot of warm temperatures in some of the components, which brings the question: How can we ever keep those warm temperatures from reaching the tank, increase the ullage temperatures, increase the flammability?

In order to make that happen, one of the ways to keep that heat from happening, so it's good to quantify how that heat is going from those packs to the center wing tank. Additional measurements within that pack bay, measuring the types of fuel transfer that is occurring from those pack components to the center wing tank; measuring the rate of heat transfer versus effective heat transfer.

Those type of measurements would be effective, and perhaps some additional verification on the acceleration measurements and also be warranted.

MR. ELLINGSTAD: Thank you, Dr. Bower.

CHAIRMAN HALL: Dr. Loeb?

(No response)

CHAIRMAN HALL: I just have one question, and I don't believe we got into the subject of the anti-static additive that is used in Europe but is not used in the United States in the fuel, and whether that had any impact on any of the tests, or how that was considered in your work?

DR. SHEPHERD: Mr. Chairman, we did not examine any fuels other than the Athens fuel. I presume that the Athens fuel does have some anti-static additive to it. There is the additional complication that the Athens fuel that we have, of course, was handled a number of times. It corresponds to the samples that we used in the flight test.

If it was desirable to have an understanding of how that affects ignition, that is something that could be perceived, but we have not done that at this time.

CHAIRMAN HALL: Kees, do you know why that is added in Europe and not done here? Does FAA know why the anti-static additive is in the European jet fuel, and not here?

DR. VAN WIN GERDEN: I'm not aware of the reason why.

CHAIRMAN HALL: Well, they told me they're going to get into that tomorrow, so I'm jumping the gun. Okay.

Well, I don't have any other questions. I just appreciate this Panel. As I said before, we have tried to put together some experts that can help us find out what caused this center tank to explode, what the ignition source was so the families would know, the American people would know, and we could fix it.

We have some very distinguished individuals here, and I hope that they feel free at any point, and any of the parties feel free, that if there are other people that need to be added to the group or other things that need to be done, that you would let us know, because we're going to stay after this.

But I'd like to close. Are there any comments you would want to share before we close?d

DR. SHEPHERD: No, sir. I would just like to thank everyone here on the Panel today.

CHAIRMAN HALL: Dr. Sagebiel?

DR. SAGEBIEL: No, sir.

CHAIRMAN HALL: Dr. Thibault?

DR. THIBAULT: No, sir.

CHAIRMAN HALL: Dr. Baer?

DR. BAER: No, sir.

CHAIRMAN HALL: Dr. Kees?

DR. VAN WIN GERDEN: No, sir.

CHAIRMAN HALL: Mr. Woodrow?

MR. WOODROW: No, sir.

CHAIRMAN HALL: Well, let me just remind the expect panel that you are spending a lot of the American tax dollars on these experiments, and we certainly hope that you will proceed with due haste, as you have in the past.

We have the international laboratories. We have the international group from Norway. We have CAL Tech. We have an outstanding group of people, and I had an opportunity to spend several hours with you all in Denver, and even though we are trying to reimburse you for this work, I was impressed by the personal commitment that each one of you brought to this effort, and I want to thank you.

Very well. That concludes this discussion on the Flammability Panel. We will begin tomorrow with the Ignition Source Panel, and we will start promptly at 9 a.m. We stand in recess.

(Whereupon, at 7:19 p.m., hearing in the above-entitled matter was adjourned, to reconvene on Wednesday, December 10, 1997, at 9:00 a.m.)