UNITED STATES OF AMERICA

NATIONAL TRANSPORTATION SAFETY BOARD

In the matter of:	*	
	*	
INVESTIGATION OF THE ACCIDENT	*	
INVOLVING SOUTHWEST AIRLINES 1380,	*	Accident No. DCA18MA142
BOEING 737-700 with CFM56-7B	*	
ENGINES, NEAR PHILADELPHIA, PA,	*	
ON APRIL 17, 2018	*	
	*	

Boardroom and Conference Center
National Transportation Safety Board
420 10th Street, S.W.
Washington, D.C.

Wednesday,
November 14, 2018

APPEARANCES:

NTSB BOARD OF INQUIRY

T. BELLA DINH-ZARR, Ph.D., MPH; Chairman, Board of Inquiry; NTSB Board Member
MICHAEL BUDINSKI, Chief, NTSB Materials Laboratory
JOHN DELISI, Office of Aviation Safety

NTSB TECHNICAL PANEL

WILLIAM ENGLISH, Hearing Officer; Investigator in Charge
BRIAN MURPHY, Structures Group Chair, Office of Aviation Safety
MATTHEW FOX, Ph.D., Senior Materials Engineer, Office of Research and Engineering
JEAN-PIERRE SCARFO, Powerplants Group Chair, Office of Aviation Safety
VINCENT ECALLE, Accredited Representative, Bureau d'Enquêtes et d'Analyses (BEA) pour la Sécurité de l'Aviation, France

PARTY REPRESENTATIVES

ERIN CARROLL, Southwest Airlines
JEFFERY GUZZETTI, Federal Aviation Administration (FAA)
ROBERT McINTOSH, The Boeing Company
JOHN ANDERSON, United Technologies Aerospace Systems
JERRY JUENGER, CFM International

PANEL 1: CFM56-7B Fan Blades: Design and Certification, Consequences of the Fan Blade Out, Inspection Intervals and Procedures

MARK HABEDANK, Engineering Leader CFM56, CFM International
CHRISTOPHER SPINNEY, Engine Certification Office, FAA
TORBEN SYBERG, Technical Fellow, Propulsion Structures, The Boeing Company
MARK WIBBEN, Senior Director, Aircraft and Powerplant Engineering, Southwest Airlines

PANEL 2: B737/CFM56-7B Inlet and Fan Cowl: Design and Certification, Structural Capability Following a Fan Blade Out Event

MARK HABEDANK, Engineering Leader CFM56, CFM International
STAN MINABE, Principal Project Engineer, United Technologies Aerospace Systems
TORBEN SYBERG, Technical Fellow, Propulsion Structures The Boeing Company
VICTOR WICKLUND, Transport Standards Branch, FAA

I N D E X

P R O C E E D I N G S

(9:00 a.m.)

CHAIRMAN DINH-ZARR: Good morning, ladies and gentlemen, and welcome. My name is Bella Dinh-Zarr, and I am a board member of the National Transportation Safety Board. It's my honor today to serve as the Chairman of this Board of Inquiry.

Today we are opening a hearing concerning the accident involving a Boeing 737-700 series, with CFM56-7B engines, operated by Southwest Airlines, which occurred near Philadelphia, PA on April 17th, 2018, that claimed the life of one of the passengers.

First, I'd like to begin by acknowledging the family members of the passenger who lost her life. Our sincere condolences for your loss on behalf of the entire NTSB. I'd also like to acknowledge the other passengers who were on the flight that day. Our thoughts are with all of you. And please know that the ultimate goal of our investigation is to learn from this tragedy so that we can prevent it from happening again to others.

An investigative hearing is one tool the NTSB may use to help complete an investigation. The hearing is being held for the purpose of supplementing the facts, circumstances, and conditions surrounding this accident. This process will assist the NTSB in determining the probable cause of the accident and in issuing safety recommendations to prevent similar accidents in the future when the final report is presented to the Board.

This hearing also provides the opportunity for the public,

for the commercial airline industry, for others to see a portion of our investigative process. During this hearing, we will examine witnesses and secure in the form of a public record, facts pertaining to the accident and the surrounding circumstances.

The purpose of this inquiry is not to determine the rights or liability of private parties, and matters dealing with such rights or liability will be excluded from these proceedings. I want to emphasize that this hearing is non-adversarial. It is a fact-finding examination.

In addition, we will not attempt during this hearing to analyze the testimony received, nor will any attempt be made at this time to determine the probable cause of the accident. Such analyses and cause determination will be made at a later date by the full Board after consideration of all of the relevant evidence gathered during our investigation. The final report on the accident, reflecting the Board's analyses and probable cause determination, will be available to the public, as are all of our investigative products.

Today's hearing will concentrate on the following issues:

(1) CFM56-7B Fan Blades: The Design and Certification, Consequences of the Fan Blade Out, Inspection Intervals and Procedures;

(2) The Boeing 737/CFM56-7B Inlet and Fan Cowl: The Design and Certification, the Structural Capability Following a Fan-Blade-Out Event.

I'd like to emphasize that while this hearing is certainly an important part of our investigation, it focuses on two specific aspects of the investigation, the fan blades and the inlet and fan cowls. Investigators also, however, have been working on and will continue to work on other issues that will not be covered in this hearing, issues such as cabin safety, operational factors, window separation, and many others.

It's important to remember that the investigative process on all factors related to this accident will continue after this hearing ends and that all factors will be addressed in our final report.

Now let me introduce the NTSB's staff who have a key role in this hearing. Serving with me today on the Board of Inquiry are:

Mr. Michael Budinski, chief of the NTSB Materials Laboratory and Mr. John DeLisi, director of the Office of Aviation Safety. Mr. Bill English is the investigator-in-charge for this accident and hearing officer for the hearing.

Members of the Technical Panel are:

Mr. Pierre Scarfo, Aerospace Engineer (Powerplants); Mr. Brian Murphy, National Resource Specialist (Structures); Dr. Matthew Fox, Senior Materials Engineer, Mr. Vincent Ecalle, who is the Accredited Representative for BEA France, which is the French government's Bureau of Enquiry and Analysis for Civil Aviation Safety.

Mr. Keith Holloway, from the Board's Office of Media

Relations, is here to assist in matters dealing with the news media. Ms. Heidi Kemner is providing support for the exhibits and audio-visuals. NTSB assistant general counsel, Mr. Ben Allen, is seated behind me and is here to provide legal support for the hearing.

Federal regulations provide for the designation of parties to an NTSB investigative hearing. These persons, governmental agencies, and organizations whose special knowledge will contribute to the development of pertinent evidence are designated as parties. The parties to this hearing have been designated in accordance with these regulations and have been selected for their technical expertise in their respective fields. Our rules of practice make clear that a party cannot be represented by anyone occupying a legal position or anyone who represents claimants or insurers.

I'll now call the names of the parties to the hearing, and as I do so, I'll ask the designated party spokesperson to please give his or her name, your title, and affiliation for the record.

The Boeing Company?

MR. McINTOSH: Good morning, Madam Chairman. Boeing would also like to express its condolences to the family who lost their loved one in this incident and its sympathy to those who were injured.

This morning at our table, we have myself, Robert McIntosh. I'm the director of product safety and investigation. Across from

me is Jim Petersen, propulsion senior chief engineer. Next to Jim is Allison Kendrick, who is principal senior counsel for The Boeing Company. Next to Allison is Mike Germani, who is a propulsion safety engineer. Across from Mike is Beth Pasztor, who is vice president of safety, security and compliance. Next to me is Eric East. Eric is one of our air safety investigators and was the air safety investigator for Boeing on the scene.

CHAIRMAN DINH-ZARR: Thank you.

The Federal Aviation Administration?

MR. GUZZETTI: Good morning, Madam Chairman. My name is Jeff Guzzetti. I'm the director of FAA's Accident Investigation Division. I'll be the party spokesperson.

To my right is Mr. David Gerlach, who is the senior accident investigator assigned as the party coordinator. To his right is Mr. Tom Boudreau, the manager of the Engine Certification Office. Across from him is Mr. Allen Rauschendorfer, senior technical specialist in the Aircraft Certification Office. Next to him is one of our witnesses, Mr. Victor Wicklund, who is the manager of the Transport Standards Branch in the FAA's Aircraft Certification Service, Policy and Innovation Division. And across from me is Mr. Mark Tomasik, our counsel.

CHAIRMAN DINH-ZARR: Thank you.

Southwest Airlines?

MS. CARROLL: Good morning, Madam Chairman. My name is Erin Carroll, and I'm the manager of air ops investigations for

Southwest. Seated with me at the table, beginning to my right, is Justin Lewis, senior services engineer; Captain David Hunt, director of safety; Mike Lindamood, senior powerplant engineer; Mark Wibben, senior director, aircraft and powerplant engineering; and Dane Jacques, legal counsel for Southwest.

CHAIRMAN DINH-ZARR: Thank you.

CFM International?

MR. JUENGER: Thank you and good morning, Madam Chairman. My name is Jerry Juenger. I am a consulting engineer in CFM Engineering and will serve as the spokesperson for the CFM team. I would like to also begin by offering CFM's condolences to those impacted in the accident, the families.

In terms of the folks at the table with me today, Ms. Benedicte Bonnet, model leader, CFM Systems Engineering; Mr. Charles Douguet, chief engineer, CFM Engineering; Mr. Doug Hensley, counsel for CFM; Mr. Michel Hugues, director, CFM Flight Safety; and Mr. David Zigan, principal engineer and investigator, CFM Flight Safety.

CHAIRMAN DINH-ZARR: Thank you.

United Technologies Aerospace Systems?

MR. ANDERSON: Madam Chairman, good morning. I'd first like to say that we would like to extend the deepest sympathy to the family and friends of the late Ms. Jennifer Riordan. We'd also like to commend the captain, crew and passengers of Southwest Airlines Flight 1380 for their actions.

My name is John Anderson. I'm our senior director of engineering at Aerostructures, a division of UTC Aerospace Systems. Across from me is Mark Wood. He is our Aerostructures Program chief engineer for Boeing programs. We have Peter Smith, who's our former head of the UTC Aerospace Systems Product Safety Board. We have Craig Bolt, who is our UTC product safety consultant. And our general counsel next to me is Christoph Feddersen.

Again, good morning, and thank you.

CHAIRMAN DINH-ZARR: Thank you to the parties.

Yesterday the Board of Inquiry held a prehearing conference in this boardroom. It was attended by the hearing's Board of Inquiry, the Technical Panel, and representatives of the parties to this hearing. During that conference, the parties were advised of the witnesses to be called at the hearing, the areas in which the witnesses will be examined, and the exhibits which will be offered in evidence. They also had the opportunity to submit additional documentary exhibits as they desired to offer at this hearing.

As we begin this morning, Mr. English will summarize the accident and the investigative activities that have taken place to date. Following this, the first panel of witnesses will be called. The witnesses have been selected because of their ability to provide the best available information on the issues pertinent to this accident. They have each been pre-qualified and their

qualifications and biographical information are available on the NTSB website.

Each witness will testify under oath. They will be questioned first by the NTSB Technical Panel, followed by the spokesperson for each party, and parties will have each 5 minutes to question the witnesses. After one round of questions, due to time constraints, a second round will be limited to pertinent questions that serve to clarify the record or to address any new matter raised as a direct result of prior questioning. After the parties have questioned the witnesses, the Board of Inquiry will question them.

As I mentioned earlier, the NTSB does not determine blame or liability; this investigative hearing is a fact-finding proceeding with no adverse parties. Therefore, cross-examination in the legal sense will not occur, and questions directed to the issue of blame or liability will not be permitted.

As Chairman of the Board of Inquiry, I will be responsible for the conduct of the hearing. I will make all rulings on the admissibility of exhibits and pertinence of proffered testimony, with the assistance of NTSB Assistant General Counsel, Mr. Benjamin Allen, seated behind me. And all such rulings will be final.

The record of the investigation, including the transcript of the hearing, all exhibits entered into the record, and the presentations, will become part of the NTSB's public docket and

will be available on the Board's website, which is NTSB.gov.

Witnesses who have completed their testimony should be aware that they may be subject to recall should the need arise. Therefore, witnesses should not leave unless they have checked with the Hearing Officer, Mr. English.

At this time I call on the Hearing Officer, Mr. English, to go over housekeeping items, summarize the accident and the investigative activities, and describe the exhibits to be used during the hearing.

Mr. English.

HEARING OFFICER ENGLISH: Thank you, Madam Chairman.

First, some housekeeping items. For all ladies and gentlemen, in the interest of safety, just take a moment to familiarize yourself with the emergency exits from the boardroom: two exits in the front of the boardroom, one to my left and one in front of me, the other side of the room below the large screens. Go down the stairs, out the door, and follow illuminated exit signs to depart the facility. You may also exit to the rear of the auditorium, the doors you came in, go up the stairs and exit straight ahead through the large glass doors to the outside. Once you've exited, turn left and follow the sidewalk to the end of the street.

In the event of an emergency, please walk quickly to the nearest exit and make your way to the outside, following the instructions of NTSB staff personnel. Do not delay. Do not

return to the boardroom until instructed or advised to do so. If you have any questions or concerns, please don't hesitate to contact any NTSB personnel.

There's no smoking, eating or drinking within the NTSB conference center area. Restrooms are available directly out the rear doors of this auditorium. Please silence your cell phones and electronic devices.

If there are no questions or concerns, Madam Chairman, I will provide a briefing on the accident.

CHAIRMAN DINH-ZARR: Please proceed.

HEARING OFFICER ENGLISH: On April 17th, 2018, at 11:03 Eastern Daylight Time, Southwest Airlines Flight 1380, a Boeing 737-700, Registration November-772-Sierra-Whiskey, experienced a failure of the left engine, a CFM56-7B, and partial loss of the engine inlet and fan cowl during climb. Fragments from the engine inlet and cowling struck the wing and fuselage, resulting in a depressurization due to the departure of one passenger window.

The flight crew conducted an emergency descent and diverted into Philadelphia International Airport. Of the 144 passengers and 5 crew members on board, 1 passenger received fatal injuries and 8 passengers received minor injuries.

The airplane was on a scheduled flight from New York's LaGuardia Airport to Dallas Love Field. The initial climb was normal, weather was good, when the crew reported that passing through 32,600 feet, they heard a loud sound and numerous alarms

indicating a failure of the left engine. A cabin altitude alarm sounded, indicating a depressurization of the airplane. The airplane rolled left about 41 degrees before the crew could stabilize it. They donned oxygen masks, shut down the engine, and began an emergency descent and diversion.

Today's hearing will concentrate on the specific events associated with the engine failure and damage to the engine nacelle. The significant components we will discuss today include the fan blades and parts of the structure around the engine called the nacelle, specifically, the inlet and the fan cowl.

The investigation found one of the left engine fan blades separated at the root due to a fatigue crack. At the time of the failure, the blade tip struck the engine fan case, resulting in a large impact load to the engine case and the fragmentation of the blade into several pieces. Portions of the fragmented blade were ejected forward into the inlet. There was significant damage to the inlet and fan cowl that was unexpected for a fan blade out, commonly referred to as an FBO event. We will discuss further details of the damage and the certification history of the engine and nacelle components today.

A portion of the fan cowl and latch mechanism struck the fuselage near the window adjacent to row 14. The impact resulted in the window departing the airplane and causing a rapid depressurization of the cabin and fatal injury to the passenger in seat 14A.

Service bulletins for fan blade inspections were in effect due to a previous CFM56-7B event; however, those were not applicable to this airplane at the time of the Philadelphia event. Airworthiness directives requiring additional inspections were issued following the Southwest 1380 accident. These will be discussed during Panel 1 this morning.

Safety issues that will be explored in this hearing via two panels today: Panel 1 will examine the CFM56-7B engine fan blade design, certification history, the consequences of the fan blade out event, and the inspection intervals and procedures applicable to the fan blades. Panel 2 will examine the Boeing 737 and CFM56-7B inlet and fan cowl design and certification, and the structural capability following a fan blade out event compared to the expected behavior.

Exhibits supporting these panels have been entered into the public docket for this investigation, which has been opened at 8 a.m. this morning.

Madam Chairman, would you like for me to now call the first panel of witnesses?

CHAIRMAN DINH-ZARR: Thank you, Mr. English. Please do.

HEARING OFFICER ENGLISH: Would Panel 1 please take the witness stand: Mr. Syberg, Mr. Habedank, Mr. Spinney, and Mr. Wibben? Please remain standing. Please raise your right hands.

(Witnesses sworn.)

HEARING OFFICER ENGLISH: Thank you, gentlemen. Please be seated. And we will begin with Panel 1, Technical Panel lead Pierre Scarfo.

MR. SCARFO: Thank you, Mr. English.

Mr. Spinney, the CFM56 is a dual-certificated engine. Please explain what this means, why it is dual-certificated, and what is the FAA's role in certification of the engine in general terms? I believe that Exhibit 7-D, pages 3 to 5, help explain this.

MR. SPINNEY: That's fine. Right. The CFM engines are dual-certificated because they are a partnership company between Safran of France and the General Electric Company of Cincinnati, Ohio. It was an agreement that was formed in the '70s to certify the engines so that they could be produced in France or in the United States. So they are directly certified by the FAA and, at the time, it was the DGAC of France, and it is now handled by European Aviation Safety Agency, or EASA.

The engine in certification terms, you know, our organization does the certification of the design based on the airworthiness standards that we've established, and we also conduct continual operational safety activities after certification. The engine itself is considered a product by the FAA, and there's three products. It's an aircraft, engine, or propeller, and what we'll talk about today is the different standards of those, which the airplane would be Part 25, and the engine parts are certified under Part 33.

Does that -- yeah.

MR. SCARFO: I've got an additional question for you. At the time the CFM56 engine was certificated back in December of 1996, what were the Part 33 requirements imposed by the FAA as they relate directly to fan blade out containment? Please explain.

MR. SPINNEY: So there are two sections of Part 33 that deal with the fan blade off event. The first is a design and construction requirement. It's section 33.19 that requires the engine fan case to contain any blade failure around the case. It can be ejected forward and aft of those cases, but the radial containment, the case has to contain the blade radially.

The second is a demonstration requirement -- it's 33.94 -- where the engine is actually tested with a full engine test, and the most critical blade, which is typically the fan blade, is released at full power on a test stand to demonstrate that containment.

MR. SCARFO: Are the certification requirements for fan blade out containment the same now as they were back in '96 when this engine was certificated?

MR. SPINNEY: Yes, they are. The rules that are currently in place have been in place since 1984.

MR. SCARFO: What is the purpose of the certification test? And what is considered a successful test or demonstration in the eyes of the FAA?

MR. SPINNEY: So the requirements for a successful

certification test is that, as I said, the debris has to be contained by the case radially. The engine is not allowed to catch fire, and the mounts attaching the engine to the structure have to stay in place.

MR. SCARFO: Thank you.

My next line of questioning is for CFM, Mr. Habedank.

As Mr. Spinney had mentioned, the CFM56 is a joint venture between General Electric of the U.S. and Safran Aircraft Engines of France. Please explain the division of labor for the engine, who is responsible for the different parts of the engine, and more specifically, who is responsible for the fan and fan blade testing. I understand that you have a few slides on this particular topic, Exhibit 8-Bravo, pages 2 through 4.

MR. HABEDANK: Okay. So the CFM International is a company formed in 1974, as Mr. Spinney indicated. It is a 50 percent ownership by GE in the U.S. and 50 percent by Safran Aircraft Engines in France. We entered service with our first product in 1984, and since then, we've grown quite a bit over 35 years. We are now at 33,000 engines shipped to over 600 customers, and our full fleet is approaching 1 billion flight hours, to put that in perspective.

As Mr. Spinney said, we design and build the engine at both sites, hence the dual-certification discussion. Specifically, the fan module which we'll be talking about today is owned by the Safran part of CFM. In simple terms, Safran owns the fan that's

in the very front, and they own the -- and they're responsible for the LP turbine, which is on the back of the engine. The middle of that, commonly called the core, is the responsibility of GE. That's very simple terms. There's other details, but that's the best way to lay it out.

MR. SCARFO: Thank you. Mr. Habedank, for certification purposes, CFM had to meet the current FAA certification requirements as well as the applicable engine certification requirements imposed by the DGAC. Can you please explain your role in how you handled both of those two certification requirements and if there was any differences?

MR. HABEDANK: Yeah. Could I get clarification, Mr. Scarfo? Are you just focused on the differences or would you like me to explain the certification process?

MR. SCARFO: Just the differences at the moment.

MR. HABEDANK: Yeah. Okay. Thank you.

There were no significant differences in the requirements between the two, so each certification test is aimed at certifying to both the FAA requirements and the DGAC requirements.

MR. SCARFO: Because it was dual-certificated, was CFM required to do a test to meet both standards or did they just have to do one test that was applicable to both the regulators?

MR. HABEDANK: Again, we ran one test that is applicable to both regulatory agencies.

MR. SCARFO: Okay. Thank you.

This question is for Mr. Spinney. Since only one FBO containment certification test was performed, please explain how the two regulators oversaw the process.

MR. SPINNEY: There's regular meetings, joint technical meetings between our colleagues in EASA, then the DGAC, to discuss the test plan. So an official test plan for any certification test is submitted to both authorities, approved by both authorities, and any details or discussions that we need to have are had, you know, regularly, with regular meetings.

MR. SCARFO: Thank you.

Mr. Habedank, the CFM56 utilizes fan blades with a large diameter chord. Please explain the difference between the normal narrow chord configuration and the newer wider chord configurations for blade design. Include in your response the advantages or disadvantages of this new design in terms of number of blades, performance, geometry, weight, et cetera. Exhibit 8-Bravo, page 8, provides a comparison of the two blades.

MR. HABEDANK: If you could, Ms. Kemner, could you please bring up the slide we just had, which is the slide 2 in the CFM exhibit?

Mr. Scarfo, I just want to put the context of the blade in perspective before I go answer your question directly.

So this here is a view of the 7B engine on the front. I've annotated two things here. One is the fan blades. There are 24 blades in the set. The other part of interest that we're going to

be talking a lot about here today is the fan case, which surrounds those fan blades and creates the flow path, or the passage of air through the fan. The whole function of the fan is to pull in air from outside, compress it, accelerate it aft, and that's what generates thrust. And the idea is to do that as efficiently as possible.

Ms. Kemner, if you could go to exhibit slide number 8 now?

So this exhibit shows a side-by-side of a narrow chord blade to the wide chord blade. Just to clarify, what we mean when we say chord, chord in really simple terms is just the width of the blade. I mean, you can see the difference there between the narrow chord and wide chord.

The big advantage of the wide chord blade is all-around thrust and fuel burn. With a bigger blade, wider chord, we're able to pump more air and we're able to pump it more efficiently. And with those two features, or with those two parameters, that's the big advantage.

There's also impact capability with a bigger blade. You're more apt to take impact or maintain a better capability to impact the blade without damage, such as bird strike, hailstone, ice, et cetera.

And then, finally, there's a big maintenance advantage. For the narrow chord blade on the left, there are 38 blades. For the 7B wide chord blade, there are only 24. So just the sheer maintainability of 33 percent, roughly 33 percent less blades is a

big advantage.

MR. SCARFO: Thank you.

Since there are fewer blades and the blades are much heavier, as far as fan blade out containment, are there differences in the approach for design and testing between the narrow chord and the wide chord configuration blades?

MR. HABEDANK: No. The regulatory requirements are the same for both wide chord and narrow chord blades. There's no difference in how we approach the test. What you said is true. On a wide chord blade, it is a heavier blade than the narrow chord, but that's all taken account for in designing the engine and setting fan case thickness, et cetera. Overall, it's a big advantage because of the fuel burn.

MR. SCARFO: Thank you.

Can you briefly walk us through the current CFM56-7 fan blade -- or fan rotor configuration? Same exhibit, 8-Bravo, slides 5 and 6, are good references.

MR. HABEDANK: Yeah. Thank you, Ms. Kemner. That's a good one to start with.

Yeah, the assembly of this is shown with the different parts in what we would call an exploded view. If you look at the sketch in the left, upper left, that's the cross-section of the engine. The color coordinates to each of these pieces. In simple terms, you have a disk, which effectively holds the blade in place, and all of this hardware rotates at speed. It's not static.

A fan blade is loaded into each slot of the fan disk, and then there's a shim put in place to protect, and that's a thin sheet metal piece that protects the blade from the -- and the disk together. Then there's a spacer which loads the blade out and not only keeps it from rattling around when they're just rotating the engine at hand speed, but it also loads it out and maintains the axial retention feature of the blade. By axial, I mean along the length of the engine. Radial is what we've been talking about.

MR. SCARFO: Thank you.

Can you please explain how CFM went about designing the CFM56-7B fan blade and fan case containment capability in preparation for the engine fan blade out containment certification test? Include in your response the development process, component testing results, the purposes of the testing, how the component testing results are used, and any significant hardware changes. I think slides 9 and 10 on that same exhibit help illustrate the point.

MR. HABEDANK: Yeah, and again, I think to just frame the reference question, Mr. Scarfo, I'd ask that Ms. Kemner go to exhibit number 3, which is that cross-section we were showing earlier. One more. There we go. Thank you.

So just to explain what we mean, we keep talking about containment, radial containment. So per the regulation that Mr. Spinney discussed, the requirement is to release one blade at the root or the attachment point to the disk. So down at the base

of that blade, where that magenta color is, is where you would be releasing it. The requirement is, as that blade is released and it impacts the fan case and breaks into pieces, none of those pieces can penetrate that fan case. So that's what we mean by radial containment.

The other criteria is that due to the vibration of a lost blade, you cannot fail the mounts with those unbalance loads, the engine cannot catch fire, and the engine configuration has to maintain its ability to safely shut down the engine. So those are the requirements that puts in perspective what we're trying to do. A lot of focus, though, on the radial containment capability in the fan case.

So now, if you will, Ms. Kemner, go to exhibit number 9 in the CFM package?

Okay. So this chart really explains the collaborative process that is executed through collaboration with the agencies, the airframer, and CFM. It is extremely complex. To put it in perspective, there's hundreds of people working on this at any given time across the different companies.

So we kind of broke it into a couple big blocks. On the top, there's the development process. That's where we're developing the design. It's not certification activity. It's all about developing, building confidence, maturing technology so that when you get to the certification test, you're ready; the expectation is that you pass.

So during this development process, any engine really starts with the key inputs. From the airframer, we get key information, in particular, fuel burn, weight of the engine, details on installation, et cetera. We have the Part 33 requirements from the agencies, and then we have our own internal design practices, requirements, et cetera. From all of that collective data, we establish a preliminary engine design.

Once we have that design, we enter this development process, where we go into detail, design, and analysis to refine the preliminary design. At that point we would run our first rig test. And I'll talk about what a rig test is here in a second to answer your question, Mr. Scarfo.

So we run this rig test, and you know, primarily for this, it's radial containment within the fan case. So if we're successful there, we may move to the next phase, which would bring that to the certification, we'd say we have a design. But more typical is to run through an iterative process, where we run several tests, we learn from all the data that's gathered, and then we, from all that process, develop what we believe is a certifiable design.

So, Ms. Kemner, if you could please go to exhibit slide number 10, I'll contrast what a rig is versus the engine test.

This shows the fan blade out rig test. This is really a simple test from a perspective of the hardware we have in there. There's some fan blades. There are also balance weights to keep

it balanced. But the sole purpose of this is to test that radial containment of the fan case. We have an air inlet in there, but it's just a test inlet. It's not representative of anything at that point.

So, again, the test conditions are that this fan gets driven by an electric motor, and we have to run that in a vacuum environment. If it wasn't in a vacuum, you'd need a jet engine to drive it to manage the flow. So that's how the test is run, with the prime purpose of demonstrating the radial containment capability.

Ms. Kemner, if you could go forward one more slide to slide 11, I'll contrast what we mean by a certification test.

So this is a full engine test run outdoors. We have this certification configuration, as I talked about. This is all of the information that we've learned throughout the process, and that's the engine we believe is certifiable.

So in this case, there's no electric motor required. We have a whole fan, or we have a whole engine, and that's what drives the fan. And we run this at full speed, and that's -- maximum rated speed is also referred to as redline speed. And we actually run the test a little bit above that to assure we have margin to the requirement.

So if you could, Ms. Kemner, go back to the process slide on number 9?

So, again, all that processing there in the development phase

was very collaborative with the airframer. There were dozens of meetings. We started those meetings in 1993, so several years before certification. And a lot of data exchanged so that both Boeing and CFM were developing their hardware in parallel with the information exchange provided.

So as I said, out of all that rig testing, we established the certification testing. Then we enter the certification process phase. And before we go to test, there's, again, lots of collaboration. On the airframer's side, the goal is to get the information -- data, loads, high-speed imaging -- so that they could witness the event after the test, things like that. There's a list of requests from the airframer. We get agreement on what that is. And then we define what the configuration is and how exactly we're going to run the test. So like I said, what speed are we going to run it, how are we going to release the blade, et cetera.

So all of that detail gets put into a formal certification report, and that certification report is passed to Mr. Spinney and his team at the FAA, and we get a formal approval of that before we can run the test. When we actually execute the test, there is an agency member there to witness the test, but there's really nothing to see in the test itself. To put this in perspective, it's over in the blink of an eye, less than a tenth of a second. The real work is after the test, where we reduce the data. We take the high-speed imaging, and we are able to slow it down frame

by frame to see exactly how the event unfolded.

So all that data, after a lot of specialist meetings, where we agree on what -- you know, we agree that, yes, that's the right data, that gets put into the engine certification report, which then would be approved by the agencies.

In addition to that, there's a formal specialist meeting, where we take all that information, review it with the agencies and the airframer, and we get agreement that that is the data, that's the proper data that came out, that the data request was satisfied. And then that pretty much sums up the process.

MR. SCARFO: Thank you.

This question is for Mr. Syberg. Before we get into any of the rig test results or the certification results, I think this would probably be a good time to discuss the various parts of the engine fan inlet and fan cowl and how they interface with the engine and airplane. In your response, please discuss who has the design and build responsibilities for both the inlet and fan cowl. Exhibit 7-Bravo, pages 2 through 4, explain that -- is a good overview.

MR. SYBERG: Okay. The inlet structure, as indicated here, Figures 1 and 2 show the inlet on the front end of a Southwest airplane, on the engine. Figure 3 starts to point to the constituent parts of the inlet. We have the outer barrel. We have the inner barrel denoted in green there, and then the front end is what we refer to as the lip skin. Figure 4 removes the

outer barrel to show visibility to a containment doubler in yellow on the backside of the inner barrel, as well as the aft bulkhead.

Ms. Kemner, next slide, please? Thank you.

The figure on the right there is a cross-section cut that, on the lower left-hand corner of that, Figure 2, shows the front end of the engine and the upstanding vertical flanges where the engine and the inlet interface. It's referred to as the A-flange. There are a series of bolts that go around the circumference that directly attach the inlet to the front end of the engine.

The constituent materials of the inlet are primarily aluminum, where the forward and aft bulkheads are made out of titanium.

The primary purpose of the inlet is to direct smooth, uninterrupted, aerodynamic flow into the engine, as well as direct smooth aerodynamic flow external to the nacelle.

Next slide, please, Ms. Kemner?

This illustrates the fan cowl. On the picture on the left the fan cowl is indicated as being in the center of the nacelle installation. Relative to the engine, it wraps around the very forward -- or the front half of the engine, around the fan case that was described earlier.

The primary purposes of the fan cowl are to direct smooth aerodynamic flow around the nacelle, but also to provide maintenance access to the engine by means of having hinges at the top and latches at the bottom. Unlatching those, the cowls at the

bottom, and holding the hinged-open cowls provide maintenance access.

Again, the primary materials for the fan cowl are aluminum throughout the skin and the stiffeners going around the circumference, and then the hinges and latches are a combination of titanium and stainless steel.

These parts, as noted here, and on the previous slides, the inlet and the fan cowl, the design requirements for these are developed by Boeing, and those were deployed to UTAS, who had the responsibility to take those requirements and develop and design and build the hardware that complied with those requirements.

MR. SCARFO: Great. Thank you.

As Mr. Habedank had mentioned, there are -- I'm sorry. This question is for Mr. Syberg. As Mr. Habedank had mentioned before, there was numerous rig tests that were done prior to the actual FBO certification test. One of particular interest is Rig Test 4, which, if my memory serves me correct, is one in which a representative inlet from Boeing was installed. My question is, is it customary for Boeing or any airframer to install airframe hardware on a rig test? And if you can maybe discuss some of the results from that rig test and if there was any corrective actions based on those results? And one other thing, I guess, what's the purpose of installing any of your hardware on an engine rig?

MR. SYBERG: Based on, you know, best practices that Boeing has developed over working with several engine manufacturers, the

interaction between an inlet and a fan case during a fan blade out event is a highly dynamic, transient event, where there's a lot of loads transmitted across the interface of the A-flange.

We had the opportunity to work directly with CFM to support the Rig Test 4 with what we believed at that time to be a production representative inlet, providing the right mass and stiffness on their end, but also allowing Boeing to understand and characterize what happens with the interaction between the inlet and fan case following a fan blade out event. Given this was in a vacuum, this was really just to assess that impact phase, where the blade hits the case and then there's a transmission of load or a ripple effect across that A-1 flange.

The results of that test indicated that a fan blade fragment which had crossed the A-1 flange had penetrated through the inner barrel of the inlet and then again of the outer barrel of the inlet. Immediately following that test, there were specialist meetings and collaboration meetings between Boeing and CFM to go over all the instrumentation and data that was reduced from that test to identify and quantify the state of the inlet following that test as well as the fan blade fragment that had performed the level of damage that it did.

Leading up to that, Boeing was able to work with CFM, and CFM defined the fan blade fragment in terms of its energy and trajectory. Boeing then took that information, developed the appropriate design requirements with added conservatism, deployed

that requirement down to UTAS with instructions to take that requirement and develop a containment doubler to protect the last half of the inlet inner barrel from a fragment that was defined by CFM.

MR. SCARFO: Thank you.

Mr. Habedank, can you please explain how the CFM56 engine fan blade out certification test was actually conducted in general terms: Fan blade release speed, how the engine is instrumented, use of cameras, data collection, et cetera? And is this the same type of technique used in previous certification tests for narrow chord blades?

MR. HABEDANK: Ms. Kemner, if you could, please bring up slide number 3 in the CFM exhibit? I think it would be the one to start with to explain.

And so using the exhibit up on the screen, again, to explain what the test is for, it's this radial containment of the fan case. So as I described before, the release is -- per the regulation -- is down at the base of that or what we would call the root or the dovetail. It's all the way down at the base of the blade.

What we do is we make a special blade and we put an explosive charge in that connected to the blade. And then when we go on to test, when we get up to the maximum speed with margin, we release that blade. And then we weigh that against the results versus the requirements in the regulations, you know, the four items that

we've said: the radial containment, the remain on the mounts, maintain ability to safely shut down, and don't catch fire. So that's how we run the test.

Relative to the 7B, we followed the standard process. I showed before where we had a full engine test. That's the standard way to run the test. It's got all the hardware that the engine would normally have on it. Again, the focus is, at the test, is testing for radial containment.

Prior to the certification test, from our process map that we showed, there are many meetings collaboratively with the airframer as well as the agency on exactly what we're going to include, what kind of imaging we're going to get, how many cameras, where they're going to be, what hardware is included, what hardware is not included, for instance.

All of those details are presented in that certification test plan ahead of actually running the test itself. The agencies are certainly involved with that. They see the formal test plan and approve it. And then with the airframer, there's multiple meetings, and they agree to the data being requested that they will use after the test for Part 25 certification activity.

As far as how we release it, I talked about that. You know, we go to the maximum speed and then some before we release the blade.

MR. SCARFO: Can you please go over in general terms the results of the fan blade out certification test, both the engine

damage and the inlet damage, as far as you're aware?

MR. HABEDANK: Mr. Scarfo, could you clarify which certification test you're talking --

MR. SCARFO: This is the fan blade out certification test, the very first one.

MR. HABEDANK: The first one?

MR. SCARFO: Yes.

MR. HABEDANK: Okay. There was radial containment. The fan case did its job. It maintained the blade radially. We demonstrated the radial containment capability. Shortly after that was demonstrated, there was another event that happened during the event which drove us to a design change on the axial retention feature of the blade.

So you asked about damage to the inlet. Because there were five blades that failed axial retention, those all came forward and did damage the inlet.

MR. SCARFO: So based on this testing, what were the corrective actions or redesigns that CFM initiated to address the release of those additional blades?

MR. HABEDANK: So we ran -- we did analysis based on the results of the test, and then we also ran several additional rigs to try to validate a new design. That design was included on the second certification test to demonstrate that that feature was -- or to validate its function and validate that it did not fail.

So at the end of the day, we used the results from the first

test, which showed the radial containment, along with the results from the second test to validate the design change, to certify the 7B to the pertinent requirements.

MR. SCARFO: And this question could be answered by Mr. Spinney or Mr. Habedank.

So was that second certification test a required test or was that something you felt you needed to do to validate the redesign?

MR. HABEDANK: Yeah, I think -- I'll let Mr. Spinney jump in after I say it, but yeah, we -- that was not a complete pass. We could not go forward with the retention feature designed as it was.

Mr. Spinney?

MR. SPINNEY: That's correct. The description he has given, is the second test was required to fully demonstrate compliance with the demonstration portion of a fan blade out.

MR. SCARFO: Okay. Thank you.

Mr. Syberg, CFM mentioned that the inlet sustained substantial damage during your test as a result of the release of the additional blades. Based on the engine FBO containment certification results, were there any modifications made to the inlet; if not, why not? And was any additional testing or redesigns performed?

MR. SYBERG: As Mr. Habedank described earlier, the types of information that we get from this test, especially from the first certification test, is -- one is an understanding of the state of

the inlet following the impact phase, and then subsequently through the engine run-down phase.

During the impact phase of the engine before the additional blades released, there was about 10 full revolutions that took place, which was about two-tenths of a second, which is a long period of time for a fan blade out event. The fan blade fragmentation that we experienced in Rig 4 that put a hole in the inlet, for which we protected with a containment doubler on this test, that happened within the first 5 to 10 milliseconds.

So we were able to obtain appropriate information and data from the first certification test to understand the blade fragmentation as it crosses the A-1 flange. That fragmentation was within the same level of fragmentation as was witnessed and observed in the rig test. And within that time frame, before the subsequent blades released, the containment doubler was observed to perform its function.

And so following that test, Boeing had confidence working with CFM as well as with UTAS, looking at the data from the test, that the containment doubler that was designed and put in as a result of the Rig 4 test demonstrated its capability in the first certification test.

A second inlet was not added to the second certification test, but Boeing had representation at the test and worked with CFM afterwards, looking at the test results, and got confirmation from CFM that the material characteristics, behavior, and the

blade fragmentation in that second cert test was consistent with the previous test.

MR. SCARFO: So just for clarification, there was an opportunity to have an inlet put on the second certification test, but based on the initial results, you deemed that it was not necessary to go ahead and retest the inlet?

MR. SYBERG: Correct.

MR. SCARFO: Thank you. Since I think we're running a little bit short on time now, maybe we can go to, like, the corrective action section.

So this question is for Mark Habedank. Can you please walk us through the various corrective actions CFM had taken to address the fan blade dovetail cracking? Can you please go over CFM's assessment of the causes and contributors of the cracking as you understand them currently? I think Exhibit 8-B, page 7, is a good illustration.

MR. HABEDANK: Mr. Scarfo?

MR. SCARFO: Yeah?

MR. HABEDANK: Could I ask you repeat that slowly again? I want to make sure I get the different pieces of your question, if you don't mind.

MR. SCARFO: Sure, sure. What I'd like you to do is walk us through the various corrective actions that you've implemented, I guess, essentially since the Pensacola event.

MR. HABEDANK: Yeah.

MR. SCARFO: But before you do that, maybe just go over your assessment of what you think the causes and contributors to the dovetail cracking are as you know them currently?

MR. HABEDANK: Okay. Thank you for clarifying. Give me one second here, please. Just looking for the right notes here.

Okay. So from the causes and contributors, let me try to explain where we, you know, where we got to during the investigation. So when we designed the 7B fan blade system, we designed it to have a lower contact pressure between the blade dovetail and the disk dovetail contact surfaces, which you can see up in the upper right chart.

When we got the results from early engines, what we call EIS, or entry into service, some of those early engines, when we looked at the fan blades, it indicated the coating system was not staying intact as well as we had anticipated with the design change.

So if you look at the lower right sketch up there, that's just a picture of the dovetail and shows the coating system. The original parts going out that were on the first engines, all they had on it was this wear coating on the blade.

After our observations of the early fleet engines, we added two things. We put a shim in place, which is just a thin sheet metal piece that goes along the length of the dovetail, and it protects the blade and disk from each other, as well as reduces friction. To further reduce friction, we now put a lubricant on, and the requirement was every 3,000 cycles you had to take the

blades out and re-lube them, or reapply the lubricant. That was all in an effort to reduce the friction level.

So from a cause perspective, root cause, why did the blades crack, that contact pressure I was talking about occurs when the blade loads out at speed; centrifugal load wants to load out against the disk, and it creates a big contact load between the two surfaces. The friction level will determine that stress. The two surfaces are sliding slightly relative to each other. The higher the friction, the higher the stress. And that's really a key contributor to understanding the cracking seen in the fleet.

So contributing factors. Like I said, the coating condition. If that coating begins to wear, it can change the loading pattern on the blade. And also, if the lubricant is either not there or since a lot of it's gone away and it's no longer doing its job, that can also reduce -- or that can also increase friction.

So lessons learned from -- you know, future, going forward, it's really all about making sure that the contributors to friction factor are addressed, contributors to the material properties, the blades go through overhaul and repair, there's new make variation, all of those pieces of variation contribute to -- can contribute to some blade cracking in the fleet.

And finally, the inspection process, which I have not gone through, but there's inspection procedures that get -- that are designed to inspect in great detail a very local area. So complementing the normal shop inspection with these --

MR. SCARFO: If I can interrupt you, if you can divide the corrective actions to the ones that were in place prior to Philadelphia and the ones that you've made since, I think that gives us a fairly good perspective of how the inspection processes matured.

MR. HABEDANK: Yeah, okay.

CHAIRMAN DINH-ZARR: And Mr. Scarfo and Mr. Habedank, I apologize for interrupting, but could the witnesses move a little bit closer to the microphone. We're having a little trouble hearing on the webcast. I think it's perfectly fine here, but the public is having a hard time hearing on the webcast. Thank you.

MR. HABEDANK: Okay. Is that a little better if I do --

CHAIRMAN DINH-ZARR: I think it's fine here. It's just for broadcast. Thank you.

MR. HABEDANK: So, Mr. Scarfo, in response to your question, you know, what we did before Pensacola was really the change shown there in the lower right. We put the re-lube criteria in place and we introduced the shim. After Pensacola, the key change to that would be we reduced the lubrication interval from 3,000 cycles to 1600 cycles, so effectively cutting it in half.

MR. SCARFO: You're talking about Philadelphia, correct, not Pensacola?

MR. HABEDANK: Yeah. I apologize. Yes.

MR. SCARFO: That's okay.

MR. HABEDANK: Yeah.

MR. SCARFO: I just wanted to clarify that those corrective actions happened after Philly. So what I'd like to kind of focus on are those action items that -- so Pensacola was the first fan blade -- and correct me if I'm wrong -- that had a separation or had even a crack detected. And then there was a set of corrective actions that CFM had taken. And then Philadelphia happened, and as we got a little bit more smart about the problem, another set of corrective actions had happened as well?

MR. HABEDANK: Yeah.

MR. SCARFO: So I kind of just want to go over those various corrective actions.

MR. HABEDANK: Yeah. Okay. Thanks for the clarification.

So after the Pensacola event, as you said, up to that point, the CFM 7B had been operating for over 20 years and nearly 300 million flight hours with no fan blade out event. So this was certainly an anomaly. The team responded very quickly. We put all resources on the issue between GE and Safran.

We worked an investigation that was really broken up into three elements. The first of those elements -- the first of the elements is around investigation and discovery, so looking at the metallography, et cetera, and then moving into development of the inspections that we talked about, and finally, the implementation of those inspections -- we may get into those details; I think because of time I'm not going to go through those right now -- with a focus on the service bulletins.

So all of that work was being done following the Pensacola event. We were able to, within 90 days of the event, we had implemented the special inspection in the shop known as eddy current, so all blades going through the shop were being eddy current inspected. And then we were developing ultrasonic inspection, which is for the fleet engines, and the fleet engines were being inspected starting with the service bulletin in March.

Leading up to that, we had worked closely with Southwest to inspect high-time blades and validate our inspection procedure. So the first service bulletin was issued in March of 2017. We revised that one time and then issued another service bulletin. As we were continuing to gather fleet data, we were changing the -- or better refining the prioritization for the blade inspections.

MR. SCARFO: So just for clarification, so prior to Pensacola, the only real crack inspection was at the repair shop and it was an FPI, but now you've incorporated some additional inspections, one that's an on-wing inspection and an enhanced inspection during repair? If you can just quickly just talk about those two items?

MR. HABEDANK: Yeah. If you could, Ms. Kemner, if you could go to exhibit slide 12 and bring that up? They kind of describe these two procedures.

These are the two inspection procedures I was talking about. The one on the left is ultrasonic. The one on the right is eddy

current. In both cases, there's a probe developed that was developed after the Pensacola event specifically for the 7B fan blade. The ultrasonic inspection on the left side of the chart is done via soundwaves going into the root of the dovetail, basically looking for inconsistencies in the material which may indicate a crack.

This is where we do this in the fleet. The practical aspect of that is during an overnight, a maintenance team will pull the blades out. They bring them into the shop, clean them up, and then do the ultrasonic inspection and an overall inspection of the blades. That is now done every 1600 cycles based on the most recent service bulletins.

The eddy current inspection, in a similar manner, has got a tool running down the length of the dovetail. And this is done with the -- the inspection is done via electrical current. And it's doing a similar thing in looking for a inconsistency in that current. This is done at the repair facility.

So as I mentioned, there's only a handful of repair facilities, so implementing the eddy current, just from a logistics standpoint, was a little bit easier. We were able to do that within the first 90 days. For the ultrasonic, since it's done out in the fleet, we needed to procure all these kits, get the kits to the operators, train them, and make sure they know how to inspect it before we put the service bulletin in place, which is why the service bulletin did not issue until March.

MR. SCARFO: Thank you.

I've got one more question, if you -- I didn't want to have Mr. Wibben feel left out. I've got one question for you. Why were the fan blades on the Philadelphia event not inspected at the time of the event?

MR. WIBBEN: So as Mr. English indicated at the beginning of the hearing today, the fan blades in the event engine in Philadelphia were not subject to either of the service bulletins that CFM had issued prior to the event, or subsequent to Pensacola, nor were they in the population of high-time fan blades that Mr. Habedank alluded to that we inspected in the months after the Pensacola event. So we really had no basis to prioritize these fan blades versus any other blades in our fleet.

In December of 2017, we made the decision to incorporate the ultrasonic inspection procedure into our regular maintenance program and look at every blade in our fleet every 3,000 cycles. In the time period between December of 2017 and the event in April -- sorry -- yeah, and the event in April of 2018, this engine was not inspected. It did not have the blade lube come due.

MR. SCARFO: Thank you.

Mr. Bill English.

HEARING OFFICER ENGLISH: All right. Thanks, Pierre.

Does the Tech Panel have any other questions to go around?

Dr. Fox, do you have any follow-up?

DR. FOX: Well, I think we're out of time.

HEARING OFFICER ENGLISH: If you have something, we can fit something in.

DR. FOX: Okay. I guess I'll just ask one quick question for Mr. Habedank.

Looking at the design fatigue life on the fan blades, they were expected to have a lifetime of 100,000 cycles or more. Could you describe the process used to determine that fatigue life of these blades?

MR. HABEDANK: So just to clarify your question, Mr. Fox, you're not asking about whether the limit -- it's just how we determine what the life is?

DR. FOX: That's correct. Just, you know, an understanding of when do you expect to potentially see cracks developing in these blades and how is that process determined?

MR. HABEDANK: Yeah. So the actual life of the blade, as I described, is very heavily dependent on the friction and other factors. So CFM at this point is still reviewing all the latest data and trying to understand how all of those contributing factors affect the calculated life, and in an effort to potentially adopt a removal threshold in the fleet.

HEARING OFFICER ENGLISH: Mr. Ecalle, any questions?

(No response.)

HEARING OFFICER ENGLISH: Madam Chairman, the Tech Panel has concluded their round of questions in the interest of time. I

believe we have a break scheduled? How would you like to proceed?

CHAIRMAN DINH-ZARR: Thank you, Mr. English, and I'll consider giving a little more time if the Tech Panel needs it after the break.

So we will take a short break until 10:25 by that clock. Thank you. So this -- temporarily adjourned for a short break till 10:25. Thank you.

(Off the record at 10:12 a.m.)

(On the record at 10:25 a.m.)

CHAIRMAN DINH-ZARR: Ladies and gentleman, we'll resume the hearing after the break. Thank you for coming back on time.

I am going to allow the Technical Panel to have more time for questioning. The parties should not be worried. You will still get your full time. I am not taking away from your time. If anything, we'll take a little bit away from my time or lunch. And again, the witness panel, if you could please move your microphones as close as possible so that everyone who's listening to this remotely can hear.

So I will turn it back over to the Technical Panel. But if I could start with Mr. Scarfo explaining a little bit more about Pensacola, which we have been hearing about and some of the other members of the audience might not be as familiar with.

Mr. Scarfo.

MR. SCARFO: Thank you. Pensacola I guess is, in some ways, a little bit of a misnomer. It actually happened in Pascagoula,

Mississippi, but because the aircraft landed in Pensacola, that's what we commonly referred to as that event. That was actually the precursor to the Philadelphia event.

It was a Southwest event. It was August 27, 2016. Very similar to the Philadelphia event. Left engine had a fan blade separation at the root, very much just like the Philadelphia event. With the fan blade separation, the inlet departed just like in Philadelphia. Parts of the inlet struck the wing and also the fuselage, resulting in a cabin depressurization. Unlike Philadelphia, the cabin depressurization was very slowly, so there wasn't an emergency as in the Philadelphia event.

So basically you had a fan blade event. You had a inlet separation event, which are similar. The difference in the two events is for Pensacola the fan cowls, they stayed in place, and in Philadelphia they did not. I think that's pretty much the details.

MR. MURPHY: Mr. Syberg, I just wanted to get back to a question that Pierre had asked you -- Mr. Scarfo had asked you earlier. What was the overall outcome as far as the structure, the Part 25 structure was concerned at the conclusion of the Rig 4 test?

MR. SYBERG: At the conclusion of Rig 4 test, the inlet which was installed had suffered some damage from a fan blade fragment that had traveled out of the engine fan case, across the A-flange, it had penetrated through the inner barrel and then subsequently

out the outer barrel. And that was at probably the last half of the inner barrel closest to the engine.

MR. MURPHY: Thank you very much.

HEARING OFFICER ENGLISH: Thanks, Mr. Murphy.

Just one clarification question I'd like to ask of Mr. Habedank on the specifics of the accident. We now have a bit of a briefing on the other event, commonly known as Pensacola, as well, and the certification rigs. If we can pull up the 8-Bravo slide 14.

Mr. Habedank, would you just please describe the actual fragmentation of the blades as we understand it from Philadelphia, the Pensacola/Pascagoula event, and from certification, and compare and contrast those? This is after the fracture at the root, the fragmentation after the blade impacts the fan case?

MR. HABEDANK: Yes, will do. You brought up the right exhibit here showing the side-by-side. So the certification blade shown on the left is typically how a blade breaks up during a fan blade out event. The tip panel is what snaps off first after the blade is released. When it hits the case, you get that tip panel that breaks off. In every one of our tests, in every one of our cert tests, that fragment has been the highest energy piece and that's the one that has moved forward, as Mr. Syberg just described, as well. So after the tip panel, there are the mid-span fragments or in the middle of the blade, tend to break up into smaller, lower-energy pieces, and then finally there's a remaining

root panel.

So the sketch on the right is, at this point, it's preliminary. The cross-party investigation team led by NTSB is still looking into all of the details around that. This is our best estimate of how we believe the blade broke up based on the remaining evidence. It broke up in a similar manner, and we expect it to break up in a similar manner, with the tip panel being similar to what we saw in cert and then multiple fragments in the mid-span region.

HEARING OFFICER ENGLISH: Thank you, Mr. Habedank.

We have no further questions right now from the Tech Panel. Appreciate the time, and we can transition to parties.

CHAIRMAN DINH-ZARR: Thank you, Mr. English.

And I apologize. I neglected to introduce one person back there, Mr. Charles Cates from Research and Engineering, who's the event data recorders expert.

So we will move now to questions from the parties. And as I said, you will have the full time. You will be on a timer. I think someone is in charge of that. And we will start with The Boeing Company.

MR. McINTOSH: Thank you, Madam Chairman. Boeing has no questions.

CHAIRMAN DINH-ZARR: Thank you, Mr. McIntosh.

FAA, the Federal Aviation Administration?

MR. GUZZETTI: Thank you, Madam Chairman. Just a few

questions.

Mr. Spinney, it was mentioned that the Part 33 fan blade out test may include an actual inlet from the installer. Why isn't a fan cowl installed on the FBO test?

MR. SPINNEY: So the fan cowl is just after the inlet. And typically during a fan blade out test what we're looking for, for data is the reaction of the fan case, which requires some high-speed video cameras. If you put the fan cowls over those, over the inlet case, you won't see any of those reactions with the high-speed video. So a lot of the information that's gathered during a fan blade out test is using that high-speed video.

MR. GUZZETTI: Okay. Thanks.

And Ms. Kemner, could you please put up Exhibit 7-D? I think it's slide 12.

And Mr. Spinney, after the Pensacola event, or Pascagoula, could you briefly describe FAA's actions or role in -- after you had discovered and participated in the Pensacola, Florida fan blade out event?

MR. SPINNEY: Sure. So after Pensacola, the FAA launches what we call our continued operational safety process. We work with CFM and operators and Boeing Company to look at, you know, a preliminary assessment of what we need to do and how fast we need to do it. In the early stages of the investigation, we're also working with the NTSB to try to find root cause. You know, so we have this continued operational safety process, the three key

elements are the root cause investigation, a risk assessment of the events, and corrective actions that need to be taken.

And I want to emphasize that those three actions are taking place concurrently. So while we're looking at root cause and digging deep into the failure of the engine and the consequences thereof, we're also looking to get corrective actions developed. I know the parties in this room were working very hard to get an ultrasonic inspection that could be done on-wing developed and implemented, and get inspectors trained during that process.

So the FAA is heavily involved in discussions about where we head with those inspections, what the risk assessment says that we have time -- do we have time to continue these actions; do we need to, you know, not -- how quickly do we have to take actions.

After the Pensacola event, given the nature of the event and the history of fan blade failures and nacelle separations, it appeared that we had time to react and take actions accordingly. And, you know, the fleet campaign to inspect engines was ongoing. We were aware of those results and those inspections that Southwest was doing, as well as other operators of the CFM engine.

And eventually -- the slide you have up there just shows the number of the milestones that we took, you know, launching the investigation in August of 2016, performing that preliminary risk assessment right after the event, deciding that we have some time to gather -- you know, develop inspections and take those corrective actions.

You know, from the beginning -- I think the inspections began in November, at least some of the early development inspections began in November. And we were monitoring those inspections right up until last month when the first phase of the mandatory inspections were completed.

We also have something called a formal risk assessment that gets very detailed, and using historical events and probabilities of different events occurring and combined, to give us a formal assessment that we can then use to compare to predefined levels that will give us some guidance on how quickly we have to act.

These decisions are made at the FAA through -- and a lot of the manufacturers share this sort of process, where we have a safety board, where it's not just the one individual looking at a problem. We convene experts and senior engineers in the office to help review the assessments and the corrective actions. We call that meeting Corrective Action Review Board, and you see there we had these various CARB meetings from March 2017, when the first CFM service bulletin came out, right up until August this past year, when we had our second supercedure of the airworthiness directive.

MR. GUZZETTI: Okay. And Ms. Kemner, the previous slide, slide 11 if you could put that up, it's basically the same thing. It's a timeline.

In the top part, Mr. Spinney, are those the CARBs you're talking about, those review boards? It looks like there were two

of them before -- right after Pensacola and before Philadelphia?

MR. SPINNEY: That's correct. So this is a bit of a busy chart, that the top line there shows time progression and the bottom line shows the various corrective actions and service bulletins that came out during that time frame. And you're correct, the FAA Corrective Action Review Boards were taken -- they correspond to the prior release of service bulletins. 1019 was the first one. The second service bulletin to come out was 1024. And then the final CARB was the revision of Service Bulletin 1033.

MR. GUZZETTI: So there is a process by which the FAA assesses risks after events such as this?

MR. SPINNEY: Absolutely.

MR. GUZZETTI: And depending on that process, is there a severity with the action that you take and what's the most severe to the least severe, I guess?

MR. SPINNEY: Sure. If you go to slide 10 on the same exhibit. So the FAA can take various corrective actions after a CARB depending on what the results of that review board has. We could write an emergency airworthiness directive for very high risk, short compliance times necessary to manage that risk; anywhere from before further flight to within 30 days, we would issue an emergency AD.

We have another tool called an Immediate Adopted Rule, where it's not quite as high as an emergency AD, but it becomes

effective shortly after we issue it and we seek public comments after the effective date of the AD.

In the final, the lower-risk category, as well, they're above the threshold. We've determined an unsafe condition, but the timeline in order to correct that unsafe condition is a longer timeline. Then we issue what's called a Notice of Proposed Rulemaking and then follow that where we seek public comment on the rule, and then publish a final rule after we evaluate the comments received from the public.

And the fourth -- obviously, if we determine that there is no unsafe condition, then we would take no airworthiness directive action.

MR. GUZZETTI: And so at the time after Pensacola -- was Pensacola the very first fan blade out of this particular blade?

MR. SPINNEY: That's correct. So our initial assessment for Pensacola was the first fan blade out in 300 million flight hours of the engine, it was a very unexpected event. And the consequences Pierre described, the consequences were a slow depressurization. So we determined early that we would require some corrective action and that it was an unsafe condition, but we also determined that we had some time and we were taking the route of Notice of Proposed Rulemaking.

MR. GUZZETTI: Okay. Thank you.

And just one final question for Mr. Habedank. That second -- I think it was Rig Test 4 -- excuse me -- that Rig Test 4 that you

described, that was specifically -- was that specifically to demonstrate the retention of the blade after that first test which showed a blade -- there was a blade out?

MR. HABEDANK: Well, there was -- might be confusing the different rigs and cert, but let me try to clarify for you.

MR. GUZZETTI: Build Test 2 -- excuse me -- Build Test 4 for the -- yeah, that's the one I'm --

MR. HABEDANK: That's okay. I'll walk through them --

MR. GUZZETTI: Okay.

MR. HABEDANK: -- for clarity so we're all straight. On Rig Test 4, as Mr. Syberg described, we had -- we liberated the tip like we always do, and that piece penetrated the inlet. We had the Boeing inlet on, on that test.

Then we ran Engine 2, Build 2, which was our first certification test. In that test, we demonstrated the radial containment capability, but then shortly after the event, seconds later, then we had the five blades released. That's what caused the damage.

When we went back for the second certification test, the purpose of that test was to demonstrate two things: One, that the design change was adequate, that we didn't release the blades again; and two, that the containment capability demonstration was not affected. So we had to still demonstrate the radial containment case still.

MR. GUZZETTI: So it wasn't meant to demonstrate the inlet

and fan cowl damage, or --

MR. HABEDANK: There was no specific reason to have had put an inlet on the second certification test.

MR. GUZZETTI: Okay. Thank you. That's all I have.

CHAIRMAN DINH-ZARR: Thank you, FAA. And I'd like to allow the witnesses as much time as possible to answer your questions, but please don't ask a question once your time is up. Just let me know, and we can give you additional time to clarify if there is time.

Southwest Airlines?

MS. CARROLL: Thank you, Madam Chairman. Southwest has no questions.

CHAIRMAN DINH-ZARR: Thank you, Ms. Carroll.

CFM International?

MR. JUENGER: Thank you, Madam Chairman. CFM has no questions at this time.

CHAIRMAN DINH-ZARR: Thank you, Mr. Juenger.

And United Technologies Aerospace Systems?

MR. ANDERSON: Thank you, Madam Chairman. We think, based on the dialogue this morning, we don't have any additional questions.

CHAIRMAN DINH-ZARR: Thank you, Mr. Anderson.

We do have a little bit of extra time. Is there any clarification questions related to the questions that have been asked by any of the parties?

(No response.)

CHAIRMAN DINH-ZARR: Seeing none, we will move on to the Board of Inquiry questions.

Mr. English, unless there's anything else that you would like to clarify from the Technical Panel related to the questions that the parties have given?

HEARING OFFICER ENGLISH: At this point, no, we'll do that as a final round after the Board of Inquiry. Thank you, ma'am.

CHAIRMAN DINH-ZARR: Thank you, Mr. English.

So now we're turning to questions from the Board of Inquiry. That's Mr. Budinski, myself and Mr. DeLisi. I will begin, followed by Mr. Budinski, and then Mr. DeLisi. And should we have time, which I think, looking from the clock, we do, we will have further questions from the Technical Panel.

So my first question is for CFM and for FAA, if you could in turn answer this question. We've been operating under the assumption that fan blades can operate indefinitely, that they don't have a life limit if they're inspected and kept in an airworthy condition. Based on this event that we had near Philadelphia and the one that we're calling the Pensacola incident, does either CFM or FAA contemplate imposing a life limit on fan blades? And if so, why or why not?

MR. HABEDANK: You okay if I go take this?

I'll take this first, Madam Dinh-Zarr.

CHAIRMAN DINH-ZARR: Thank you, Mr. Habedank.

MR. HABEDANK: Yes. So, you know, we've got this inspection

in place. We didn't talk too deeply about it this morning, but we've got a very, a very robust inspection plan that manages the safety of the fleet. It's managed via airworthiness directives, which makes the CFM service bulletins a requirement. That in simple terms is how we're managing the fleet.

With that said, we're still looking at the adoption, reviewing the adoption of a removal threshold. If we take a step back, the requirement for life-limited part, it's defined by the regulatory agencies as a critical part whose failure could result in a hazardous engine condition. By virtue of the testing we go through and the certification reports approved by the agencies, we are demonstrating that that failure through that fan blade out test does not present a hazardous engine condition, which is why it's not a life-limited part, and it's not a requirement to this day to do that.

CHAIRMAN DINH-ZARR: Thank you, Mr. Habedank.

And Mr. Spinney?

MR. SPINNEY: Yes. I would just add that, you know, while fan blades are not typically life-limited because the regulations prevent them from being a critical part under the demonstration test and under the design requirements; however, it's not impossible to decide to life limit a fan blade. We have done it in the past on some occasions when the frequency of those failures became an unacceptable condition. In this case, I don't think we've made any decision one way or another whether the blade needs

to have a life limit on it, but we will be looking at that in the future as the investigation and the corrective actions proceed.

CHAIRMAN DINH-ZARR: Thank you very much, Mr. Spinney.

And just to clarify, I know that those in the aviation industry are very aware of this, but fan blade out incidents are something that the industry and safety experts, we control for, that we know will happen, but -- and that's why we have the certification process. I mean, just to make it completely clear for people, I think sometimes it's difficult in a very technical forum like this for the public to understand that.

My next question is for Southwest Airlines. Would you describe Southwest's response to the emergency airworthiness directive, which we call ADs, issued following Flight 1380 and the subsequent revisions?

MR. WIBBEN: Thank you, Madam Chairman. Certainly. So at the time of the Flight 1380, Southwest Airlines had already been performing ultrasonic inspections on our fan blades as well as eddy current inspections of the blades when they were in the shop. So at the time of the event, we had already inspected 603 engines.

The first airworthiness directive that came out on April 20th, 2018, that'd be AD-2018-0951, was effective to 286 of our engines. All but 85 had already been inspected per those prior efforts. The remaining engines were inspected over the next 5 days, and we were completed with those inspections and compliant with that airworthiness directive by April 25th, well within the

20 days that was required by the airworthiness directive.

We then went on and continued to inspect our fleet until -- through May 18 -- or May 17th, 2018. At that point we had inspected every engine in our fleet. So the following ADs, 2018-0910 and 2018-1011, we were compliant with either when they came out or prior to them coming out.

And then, finally, in July, CFM had indicated to us that they were going to recommend reduced inspection interval from 3,000 cycles to 1600 cycles. So at that time, we began accelerating our inspections such that on August 2nd, 2018, we could say that no operating fan blade in our fleet had gone longer than 1600 cycles since its previous inspection. And so the airworthiness that recently came out in October 2018, 1801, we were already compliant with that by the time it was released.

CHAIRMAN DINH-ZARR: Thank you very much. And did you have any difficulties performing the inspections, such as in the tooling or training or instructions or the pace of inspections? Because it seems like you completed them fairly rapidly.

MR. WIBBEN: So the inspection, we schedule it with the fan blade lube. So the blades, when they're already out, you clean the blades, essentially, and take the ultrasonic probe to inspect the blade, the blade dovetail, as was -- as shown earlier in the hearing. So all told, getting the blades out, performing the inspection, putting them back in and running the engine, is about a 5 or 6-hour job that can be done on a maintenance overnight.

At the time of the Philadelphia event, we had done this inspection 600 times, so we had a fair amount of experience with it. Certainly doing the number of inspections that we did in the time frame -- within a month, we did 900 inspections. So within that time frame, it certainly presented some logistical challenges in terms of routing aircraft to maintenance facilities and things like that, but we were able to manage through it and get it done.

CHAIRMAN DINH-ZARR: Thank you. I'm going to try to keep within my own instructions as well and ask one last question in this round, of FAA.

Mr. Spinney, so it's my understanding that CFM had issued some service bulletins prior to the Philadelphia event that we're talking about today. Did the FAA issue any ADs based on these service bulletins prior to April, and could you explain briefly?

MR. SPINNEY: So we had not issued what's considered the final rule airworthiness directive. We had begun the airworthiness directive process and had issued a Notice of Proposed Rulemaking. We had received the public comments to that rule and were in the process of responding to those comments and developing the final rule at the time.

CHAIRMAN DINH-ZARR: Thank you, Mr. Spinney. I appreciate that clarification --

MR. SPINNEY: Sure.

CHAIRMAN DINH-ZARR: -- on the timeline.

My time is up, and so I will turn over to Mr. Budinski for

his questions.

MR. BUDINSKI: Morning. My main question at this round will be for Mr. Habedank. It's a multi-part question, but I'll just ask one part at a time.

The fan blade roots are shot-peened to impart residual compressive stresses at the blade roots. And that's exactly where the accident fracture occurred in this event. Residual compressive stresses from the shot peen are generally to aid the initiation or to control the initiation of fatigue cracks in the blade root. In other words, they prevent or prolong the initiation of fatigue cracks in the blade root.

And during the laboratory work that was done at NTSB and elsewhere, the materials lab report documented a loss of residual compressive stresses in some of the fan blade roots tested from the accident engine. I want to say I think it was six fan blades that were evaluated. And so assuming that those residual compressive stresses were within design tolerances when the blades were new, it's perceived that there was a loss in residual stress, residual compressive stress. The report also documented some small cracks in some of the blades, which can be an indication of loss of residual compressive stress, as well.

So my first question is: How is residual stress factored into the modeling of fatigue crack initiation life of a fan blade?

MR. HABEDANK: We account for the residual stress in a standard manner of doing that. We do not take credit for that

residual stress from shot peening. So, for instance, in the coating process, the coating process can create perturbations or things on the surface, but by shot peening that, as you described, you put a compressive layer, and it makes it much less sensitive to any of those things.

So in our processing, the way we account for it is that with the combined processing, it's net back to standard material properties.

MR. BUDINSKI: Okay. So what you're saying is that this just helps to provide a more conservative fatigue analysis?

MR. HABEDANK: Yes.

MR. BUDINSKI: Is the mechanism of residual compressive stress loss understood at this time, and is the residual compressive stress loss interrelated with tribological characteristics of the dry film lubricant? Do you have any kind of understanding in that area?

MR. HABEDANK: Yes. The presence of the coating or not, from a material perspective is irrelevant. But the loss of coating, as I described earlier, can lead to higher friction levels, which can raise the peak stress in the area of interest that we're discussing. So we have not confirmed one way or another, but as you said, we have seen blades that have a loss in residual stress.

There's really two possibilities for that. One is that the stress level is so high with the high friction, that you -- in that stress condition, you'll actually relax out the compressive

stresses put in the material by the shot-peen process. The other thought process is during the overhaul process where the coating is reapplied, there may be something in that processing that affected the residual stress. We have worked that very hard for 2 years now, and we have not been able to lock that down with the data that we have.

So it's one or the other, so we have implemented process checks, audits at the supplier, to make sure that we have a robust coating process that won't lead us down a material degradation issue.

MR. BUDINSKI: Okay. But there's no -- so you don't really audit compressive residual stress on a basis -- like once you have a process set up, you do your parts and it's not monitored over time? So blades aren't ever checked further in their life?

MR. HABEDANK: And that would be standard process for any part.

MR. BUDINSKI: Right.

MR. HABEDANK: The way we use that practically in the industry is we set up a shot-peen process, and that's all of the parameters. It's what material is the shot peen, what size is the shot peen, what pressure do you apply it, how far away are you, all of those parameters. And then we run a sample piece that's called an Almen strip. And it tells us, for those given processes, you will get this much residual stress. We apply that same process to the blades, and the expectation is that's what you

get in the blade from a compressive layer.

MR. BUDINSKI: Okay. Thank you.

One last part to this question. Regarding risk analysis to determine inspection and overhaul intervals, how would the loss of residual stress influence a determination of overhaul intervals?

MR. HABEDANK: The loss of residual stress is really built into all of the field data that we're getting, as far as the data from the inspections -- where we have found the cracks, how old they have been, what is the crack propagation rate. All of those parameters go into determining what the right re-lube is from a risk perspective. But I wouldn't say the actual -- that physical number is included in it. It's in turn really included in all of the other data, that effect.

MR. BUDINSKI: Okay. Thank you. That is my question.

CHAIRMAN DINH-ZARR: Thank you, Mr. Budinski.

Mr. DeLisi?

MR. DELISI: Thank you.

Mr. Habedank, had the Pensacola blade already been inspected prior to its failure?

MR. HABEDANK: I believe from the records, that the last inspection was in the shop during overhaul in 2012.

MR. DELISI: And what type of inspection was that?

MR. HABEDANK: That would have been our standard shop inspection. It's called fluorescent penetrant inspection.

MR. DELISI: FPI.

MR. HABEDANK: FPI.

MR. DELISI: So when the blade failed, did the striation count indicate that the crack already existed at the time of its previous inspection?

MR. HABEDANK: Yes. The data suggests from the metallography and the striation count from the crack, that --

MR. DELISI: Okay.

MR. HABEDANK: -- the crack was approximately 60-thousandths deep at the time of the inspection.

MR. DELISI: Had the Philadelphia blade been inspected prior to its failure?

MR. HABEDANK: I'm sorry, sir. I think I need to correct the previous statement. I caught -- what I heard was you were asking me about Philadelphia, but your first question was on Pensacola?

MR. DELISI: I did want to walk through for both.

MR. HABEDANK: Yeah, okay.

MR. DELISI: So --

MR. HABEDANK: So, if you could, please, give me a second, and let's go back, and --

MR. DELISI: All right.

MR. HABEDANK: I want to make sure I get the record straight on which one. I apologize. I jumped into the wrong one.

MR. DELISI: Great. So let's go back. We're talking about two blades that failed in service, the first one being Pensacola. Had that blade been inspected prior to its failure?

MR. HABEDANK: Yes. That's the data I'm trying to pull up here. Just give me one second, please.

MR. DELISI: Okay.

MR. HABEDANK: As for the Pensacola blade, looks like our last inspection of that, last time it was in the shop, was at about 20,000 cycles, when the shims were put in, and the failure on that one was at 38,000. So the crack in that one did not initiate prior to that inspection. It initiated after the inspection based on striation count.

MR. DELISI: Okay. So now on to the Philadelphia blade.

MR. HABEDANK: Yeah.

MR. DELISI: Had it been inspected prior to its failure?

MR. HABEDANK: Yeah, so it was inspected in 2012, as I indicated. It, at the time, had about 20,000 cycles of operation on it, on those blades, and the failure occurred with approximately 32,000 cycles. And --

MR. DELISI: So did the striation count indicate that that crack had already existed at the 20,000 cycle time?

MR. HABEDANK: Yes. So the -- if we look at the striation count and go backwards, it appears that during that inspection in 2012, the size of the defect was about one-sixteenth of an inch, or 60 mils.

MR. DELISI: And is that the level of threshold that you would expect detection using an FPI technique to catch?

MR. HABEDANK: That's lower than what an FPI is capable of

doing on a repeated basis.

MR. DELISI: So is there a better inspection technique out there to determine if a blade root is cracking?

MR. HABEDANK: Yes. It's the inspection we have implemented now, either the ultrasonic inspection done on wing or the eddy current, which is even more refined, in the shop.

MR. DELISI: And how often is that inspection required?

MR. HABEDANK: In the shop? Which specific -- so the --

MR. DELISI: I'm asking you about an inspection technique that's more effective than an FPI.

MR. HABEDANK: Right. So there's two inspections. The ultrasonic requirement is that they -- that the operators inspect it every 1600 cycles, and it has to be -- go through the sonic inspection. An alternative to that is if the blade happens to be in the shop, they can inspect it in eddy current there. Both inspections count towards the -- count as credit towards the service bulletin. But I will clarify, too, sir, that all blades that go through the shop for overhaul do get eddy current inspected.

MR. DELISI: Okay. So using the new techniques that are in existence since Philadelphia, have any blades been pulled from service because a crack has been detected?

MR. HABEDANK: Yes, we have.

MR. DELISI: How many of those?

MR. HABEDANK: There's been a total of eight crack findings

since the Pensacola event.

MR. DELISI: So it's great that the inspection technique is pulling those parts from service. But that's a lot of blades that are cracking. Is this a surprise to CFM to see blades being pulled from service long before the expected fatigue life?

MR. HABEDANK: Well, yes, unexpected up until a couple of years ago, until we understood the problem. What we're seeing now, based on our new knowledge, material testing, evaluation, the data we're getting from the field, we have a good understanding of why we're seeing it. And the number that we're seeing is consistent with our analytical model.

MR. DELISI: So there's been some talk about the lubrication of those blades and that may be critical to helping to keep those stresses from accumulating.

Mr. Wibben, can you describe what it is that Southwest does when they're re-lubing a blade?

MR. WIBBEN: Sure. So in order to do the lubrication task, the fan blades are removed from the engine and the dovetails are cleaned. And there is a lubricant that we brush onto the blade to restore the lubrication. That lubricant is initially applied at overhaul, and then now it's every 1600 cycles after that.

MR. DELISI: And what is that brushed-on lubricant?

MR. WIBBEN: Give me one moment.

MR. DELISI: Okay. And I'm going to ask Mr. Habedank, is that CFM's instruction, to apply this particular brushed-on

lubricant?

MR. HABEDANK: Yes. Southwest is compliant with the CFM recommendation. There are multiple options in the manual to allow. One of them is a spray-on lubricant; others are brush-on. And that is the -- that's typical for fan blades. And again, Southwest is compliant with their actions.

MR. DELISI: Giving Mr. Whitten a chance -- Wibben -- I'm sorry -- a chance to catch up with his research.

MR. WIBBEN: Yes. It is a Molykote paste, a thin coating of a lubricant that's called Molykote.

MR. DELISI: Gotcha. And in applying that lubricant, is there a measured thickness that has to be achieved? How do you know if the lubrication has been properly applied?

MR. WIBBEN: The aircraft maintenance manual, which we write into a task card, gives the mechanics instructions on how to apply the lubricant to know that they've done it correctly.

MR. DELISI: Mr. Habedank, when the blade first went into service, I think you described a re-lubrication interval that was somewhere between 1500 and 3,000 cycles; is that correct? At some point in the blade's early history was there that range of availability for when the lubrication could be reapplied?

MR. HABEDANK: No. Let me clarify. When we went into service in '97, we did not have a lubrication requirement for the dovetail. It only included the wear coating on the blade. After the early engines were not coming into the shop, but as we got --

looked at them as the blades were being inspected, we noted that the coating distress was more than we had anticipated. So that's when we introduced the first requirement for re-lubrication, which was every 3,000 cycles. That's put in the MPD, which is a mandated document owned by Boeing.

MR. DELISI: And --

MR. HABEDANK: We later -- oh, I'm sorry. We later --

MR. DELISI: And now that cycle is down to 1600 cycles?

MR. HABEDANK: 1600 cycles. We made that change just recently.

MR. DELISI: Thank you.

CHAIRMAN DINH-ZARR: Thank you, Mr. DeLisi and Mr. Budinski for the questions.

I would like to give the Technical Panel a little more time since we have some time remaining to continue or ask new questions as needed. Mr. English?

HEARING OFFICER ENGLISH: Thank you, Madam Chairman. Mr. Scarfo has some follow-up questions for the Panel.

MR. SCARFO: My first question is for Mr. Habedank. Mr. English had asked previously to compare and contrast the fragmentation from the certification in the Pensacola and Philly events. Can you clarify where the fragments went in cert and compare those with those of the two events?

MR. HABEDANK: Yes. The fragment from the certification engine, Engine 2, Build 2, went forward just as it did in all

other nine tests. Those nine tests I referenced are the two certification tests and then the eight -- total of eight rig tests. That tip panel is always the highest energy piece and always goes forward. The breakup is as I described earlier, with the tip fragment being pretty consistent, then a series of smaller, lower energy fragments in the mid-span, followed by the root panel.

For the Philadelphia blade -- excuse me. Let me ask a clarifying question, Mr. Scarfo. Did you ask me Philly or Pensacola or both?

MR. SCARFO: Both.

MR. HABEDANK: Okay. So for the Pensacola event, we did not -- we were not able to obtain the hardware because the event happened over water. But based on the evidence, we -- the tip did go forward in that event.

And then, in the Philadelphia event, the chart I showed earlier highlighted that based on preliminary evidence and our assumptions given the data we have, it appears that the blade breakup on the Philadelphia blade is consistent with that of the certification test. What all that fragmentation means to the follow-on events is still being determined by the cross-party team led by NTSB.

MR. SCARFO: So from what I gathered, the certification test and the Philadelphia test look very similar, but there's a uniqueness to Pensacola that wasn't seen in Philly and wasn't seen

in the certification test. Can you please explain that difference?

MR. HABEDANK: Yes. In all of our other testing, including the Philadelphia test, the root panel, it gets pulled aft, and it lodges in the -- what's called outlet guide vanes right behind the fan. So that's where we typically would find the root panel. In the Pensacola event, it appears that that root panel did go forward and was not recovered.

MR. SCARFO: And I'm sure Brian will probably ask questions in the afternoon section, but during the design of the inlet, that's something that's not accounted for because that's not something that's ever happened before, correct?

MR. HABEDANK: That's true. The only event we have with the root panel, any evidence of the root panel going forward was the Pensacola event.

MR. SCARFO: Great. And if I've got time, I've got one additional question. This is for Mr. Syberg.

This is in relationship to Rig Test 4. I think we kind of glossed over it a little bit that the importance of Rig Test 4 from the inlet's perspective, that was the first, and if I recall, that's the only time that a production representative inlet was installed on a rig prior to the certification test. Based on the damage that you saw, what were the corrective actions or redesigns that Boeing undertook to address the damage that was observed in Rig Test 4?

MR. SYBERG: Following Rig Test 4, we worked directly with CFM to fully understand the fan blade fragment definition that went through the inner and outer barrel of the inlet. Upon definition from CFM of the exact parameters of energies and trajectories, Boeing then put a conservative estimate on that to develop a requirement, which was then deployed to UTAS who was responsible for the design and development of the inlet, and with instructions in those requirements to develop a containment doubler to be able to contain the fragment as defined from Rig Test 4 with a conservative level estimate above that.

MR. SCARFO: So just for clarification, Rig Test 4 had a representative inlet without a doubler or containment shield, and for the certification test, that's when you had a representative production inlet with a containment shield?

MR. SYBERG: That is correct. And then through the post-test investigation of the data from the certification test, we were able to follow the fragmentation going into the inlet and get observations that the containment doubler was not penetrated during the certification test.

MR. SCARFO: Excellent. Thank you.

That's all I have.

HEARING OFFICER ENGLISH: Thank you, Mr. Scarfo.

I'd like to follow-up just along that same line of questioning a little bit and speak about some of the specifics of Philadelphia.

Now, Ms. Kemner, if you pull up, I think, visually, to help the audience, the opening presentation slide 5.

We have -- you mentioned, Mr. Habedank, during the rig testing there was one of the tests in which the axial retention failed where the five blades came out. I just want to make sure that we clarify for the record, and if you can describe where on the slides this is: During the actual event in Philadelphia, that axial retention was not an issue; is that correct?

MR. HABEDANK: That's a true statement. Thank you for the clarification.

HEARING OFFICER ENGLISH: And can you just describe for the audience where that failure, that problem was in the tests using these exemplars here that are not failed?

MR. HABEDANK: Yeah. Actually --

HEARING OFFICER ENGLISH: Is it visible enough in there?

MR. HABEDANK: Yeah. I mean, towards the back of the blade -- hold on. I think our 3-D view of the assembly might be best way to answer that, Mr. English.

So, Ms. Kemner, could you please go to exhibit number 5? That might be the cleaner way to demonstrate or respond to Mr. English's question.

So you can kind of see on that, on the fan blade, at the base of it, on the back side of it right where the dotted arrows are showing how it slides in, there's a little hook there. And then there's features on the disk and mating part, as that hook goes

back and the spacer pushes outboard, it gets locked in place. That's the feature we're talking about.

HEARING OFFICER ENGLISH: Okay.

MR. HABEDANK: And that feature is in there so that during -- with normal operation, you got a heavy aero load with all that air pumping. Without some kind of axial feature, it would just shove the blades forward.

HEARING OFFICER ENGLISH: Okay. Great. Thank you, sir.

If we can go back to the other photos, and let's just talk through Philadelphia a bit. So we have -- we know for Philadelphia, just one, the one blade failed, failed at the root. The axial retention was not an issue. We have a photo here that was mocked up. We used -- these are just 3-D -- the white things are 3-D-printed representations of those fragments that you showed before.

Can you just describe for the record what we're seeing here with those fragments, what's trying to be displayed there -- this was just done in the hangar -- and where the parts are in relation to the A-flange and the containment doubler with these mock-ups so we can just describe the trajectory that we see from the Philadelphia event?

MR. HABEDANK: Are you directing that to me?

HEARING OFFICER ENGLISH: Yes, to Mr. Habedank.

MR. HABEDANK: Okay. So just, I want to make sure I understand exactly what you're looking for. Can you --

HEARING OFFICER ENGLISH: Yeah, just describe what we're seeing here with these fragments. So these are similar -- this is what we think we see in the Philadelphia event.

MR. HABEDANK: Okay.

HEARING OFFICER ENGLISH: And you mentioned earlier that you think that's similar to what you saw in certification, correct?

MR. HABEDANK: Yes. Thank you. With this in-process work that's being done, what happens -- well, let's focus on the tip panel because that's very consistent. It's the highest energy piece. It doesn't just come straight out forward because it's got rotational energy. It's sliding almost like a marble around the inside of the nacelle itself. As it's doing that, it's also coming forward. So there's a helix angle that's associated with the trajectory, which is where a lot of the focus of the investigation is. These are the witness marks on the case that define what that spiral or helix angle is for each of the particles.

HEARING OFFICER ENGLISH: Okay. Very good. So you saw a similar or a type of helix angle during the certification tests, correct?

MR. HABEDANK: Yes.

HEARING OFFICER ENGLISH: Is that part of the information that is passed from the engine manufacturer to the airframer?

MR. HABEDANK: Yes. There's a formal documentation with the airframer, and there's also a agency-approved document that

documents for that highest energy component piece, the tip, we define the mass, velocity, and this spiral angle, which gives them the full level of energy.

HEARING OFFICER ENGLISH: Was that revisited at all after the test which resulted in the addition of the containment doubler?

MR. HABEDANK: I don't know specifically if that was discussed, Mr. English. There were a lot of follow-on tests, and there were -- sorry -- there was a lot of follow-on meetings following the certification tests. I'm assuming as part of that -- we know we gave all -- we discussed all of the rig testing results, et cetera, along with the cert. I'm assuming that was brought up in there, but I can't say that for sure.

HEARING OFFICER ENGLISH: Okay. Thank you.

Just from the FAA perspective, Mr. Spinney, can you describe are there particular criteria that the FAA sets either in regulation or advisory material for what type of information is transmitted from this type of test?

MR. SPINNEY: Yes. The design criteria in 33.19 requires that the energy and the trajectory of those parts that are experienced during blade-off tests, anything that goes outside of the engine cases, that trajectory needs to be defined. Typically, they are defined in what's known as the installation manual, which is also required by regulation 33.5.

And just to go back a little bit, the trajectories that are in the installation manual are based on the final certification

tests, in the prior certification tests. So they all were -- came after the rig tests that you were talking about.

HEARING OFFICER ENGLISH: After that Cert 2/2, correct?

MR. SPINNEY: Yes.

HEARING OFFICER ENGLISH: Right. Okay. Thank you. That's the end of my questions.

Matt? Dr. Fox has some questions?

DR. FOX: Thank you.

I guess, Mr. Habedank, you had mentioned earlier during a prior line of questioning, you mentioned about not taking credit for the shot peen surface condition and also, you know, referenced standard material properties. Could you describe a little bit what you -- or how you determined the standard material properties with regard to fatigue life?

MR. HABEDANK: Yes. For the original design of the life -- or sorry -- for the original life of the initial design, we used standard titanium material properties for the blade and then made assessments with that. Part of our root cause investigation, we wanted to get a better material curve, so we actually took multiple blades and took specimens out of specifically forged blades for -- forgings for 7B blades, and re-looked at the material properties to get a better definition. Those results were then used in our life analysis and to correlate those lives to what the observations are in the fleet. And that's where we have a good, solid correlation.

DR. FOX: And could you also describe, you know, was there any component-level testing done to determine fatigue life or was it all based on the material properties and analysis?

MR. HABEDANK: Material properties and analysis. So we have a 3-D model of the bladed disk, you know, the full assembly. We'll run that in several conditions, look for the peak stress, the min stress, and go into the LCF curve with that. But it's straightforward in that the main load is the centrifugal load of the blade onto the disk dovetail. That reaction, along with the friction, is what gives you your stress in the area of interest.

As I stated before, there's a lot of different ways to look at that friction factor because of the coating conditions. So it's not one number for the life of the blade, which makes that life analysis more complex, and that's why we correlate it back to fleet observations and tie it together.

DR. FOX: Very good. Thank you.

And then I just had one -- well, maybe a couple of questions to follow on regarding the additional findings in the field, crack findings in the field following Pensacola. I guess I just want to clarify that, you know, without naming any specific operators, you know, could you describe overall what operators you have seen or, you know, just kind of in a general sense, in that it's not just Southwest Airlines operator?

MR. HABEDANK: Yes. Let me -- I want to get to my table of data so that I don't speak out of turn here. I want to make sure

I give you the facts here. Here we go. Yeah, there were -- so in the Philadelphia event there was one failed blade. In the Pensacola blade set, there was one failed blade, six others with cracks. So we count that as eight cracks seen on the two event engines.

Outside of those two event engines, there are a total of eight findings to date, and those are spread across different operators. Four of them are at Southwest. Four are not at Southwest. And the explanation for that is pretty simple. Southwest was the EIS customer. They took delivery of many of the early engines, and we would expect, based on their quantity of engines, they're about 10 percent of our fleet, 1500 engines out of 15,000. It's not a big surprise that they would have a bigger content than some others.

DR. FOX: And, you know, as far as inspections, are they going to be -- are they consistent across the fleet as what you're seeing both domestic/international operators?

MR. HABEDANK: There's no difference in that. Everybody is using the same equipment, so there's no difference. They've all been trained.

Part of our incorporation of these two new inspections, the eddy current and the ultrasonic, primarily the ultrasonic, we had to train 250 operators around the globe to be able to use this inspection, as well as some other MRO shops that were, you know, third-party sources to assist. So there was a huge effort in late

2016, early 2017 to get ready for those service bulletins. And a big part of it was training so that everybody is using the same equipment, they understand how to read the equipment, and that, you know, they're not doing something unique.

DR. FOX: That's all I have. Thank you.

HEARING OFFICER ENGLISH: Great.

Mr. Murphy?

(No response.)

HEARING OFFICER ENGLISH: Madam Chairman, the Tech Panel rests.

CHAIRMAN DINH-ZARR: Thank you very much, Mr. English.

And thank you for being so forthcoming, all the witnesses. We appreciate your taking time to answer these technical questions so carefully, and referring to the documents.

I think we are going to finish this session early, which will allow you more time for lunch and to get back through security this afternoon. But we will start at the same time we were planning to start because there are people who have planned their day around this who are watching remotely.

So I'm going to adjourn for lunch now, which is 11:26, and we will re-adjourn at 12:45 p.m. in this room.

Thank you.

(Whereupon, at 11:26 a.m., a lunch recess was taken.)

A F T E R N O O N S E S S I O N

(12:52 p.m.)

CHAIRMAN DINH-ZARR: We're starting a little bit late to let the rest of the security line get through.

(Pause.)

CHAIRMAN DINH-ZARR: Good afternoon, ladies and gentlemen. I'm going to reconvene this hearing. And I did realize that before I said re-adjourn, so you know what I meant, reconvene.

And now I will turn it back to our hearing officer, Mr. Bill English to recall the witnesses.

HEARING OFFICER ENGLISH: Thank you, ma'am.

The afternoon panel of witnesses, please take the stand: Mr. Syberg, Mr. Habedank, Mr. Victor Wicklund from FAA, and Mr. Stan Minabe from UTAS. And remain standing. Please raise your right hands.

(Witnesses sworn.)

HEARING OFFICER ENGLISH: Thank you, gentlemen. Please take a seat. And the afternoon Panel 2 will begin with Tech Panel lead, Brian Murphy.

MR. MURPHY: Good afternoon, Madam Chairman, gentlemen. I'd like to start with Mr. Wicklund and just get us level, set for the afternoon on -- as far as Part 25 and Part 33 elements. Could you tell us what belongs to who?

MR. WICKLUND: Yes. If we could refer to Exhibit 7-D, slide 4? So as you can see, at the bottom of this slide, the

delineation between Part 25 and Part 33. The Part 25 is the transport category airplane standards. Part 33, aircraft engine standards.

If we move to slide 5, please? The Part 33 engine standards apply to the engine. The Part 25 standards apply to the engine installation, including the items highlighted here in red, the inlet, the fan cowl, the strut, nozzle, and plug and thrust reverser.

MR. MURPHY: All right. Great. Thank you, Mr. Wicklund.

Could you please let us know what the acceptable means of compliance for the design and certification of the inlet and the fan cowl are?

MR. WICKLUND: Certainly. If we refer to slide 13, please, of Exhibit 7-D? Thank you. Must be the next one. Thank you.

So basically the requirements for the engine inlet and the other major nacelle components is for the airplane manufacturer to show that they are safe in the event of a fan blade out event.

In this case, the airplane manufacturer would show that in the event of a fan blade out event, the result would -- fan blade out event -- excuse me -- would be a foreseeable single failure and that the result couldn't jeopardize the safe operation of the airplane. In the case of the engine inlet being the mass that it is, generally that requires that they retain the inlet in a fan blade out event.

MR. MURPHY: (Off mike) -- even without that, but okay. Back

to the -- what I was getting at with the acceptable means of compliance. More straightforward, is it required that the inlet or the fan cowl actually go through a structural test as an assembly, as an entire unit, or can it be certified through analysis alone?

MR. WICKLUND: Either way would be fine. You could either test it or conduct analysis based on tests.

MR. MURPHY: Great. Thank you.

This would be to follow up from a question from this morning that was already addressed, but -- I'll have this in two parts, and Mr. Wicklund or Mr. Syberg, either one of you could answer it. One will answer the other.

Is there a requirement, then, for a production inlet during the certification tests? And then what would follow with that question is -- let's just go with that for right now, then. Thank you. Either --

MR. WICKLUND: Oh, so there is not a requirement for a production inlet. As was discussed earlier, they could use representative components to simulate the mass stiffness of the inlet during a Part 33 test.

MR. MURPHY: I was asking just then -- so for clarification, because we talked about rig tests and we talked about actual certification tests. So even for those engine Part 33 certification tests, it is not required by the FAA or -- well, we're not going to speak for -- DGAC is here -- EASA, but by the

FAA, then, to have production hardware for the inlet on their test?

MR. WICKLUND: That is correct.

MR. MURPHY: Okay. Oh, yeah, wanted to get you closer to the mike, I think.

MR. WICKLUND: Oh, of course.

MR. MURPHY: This was done back in 1995 and, you know, we're now in 2018. Have the acceptable means of compliance for, you know, accepting the -- for substantiating the inlet or the fan cowling changed in that time period?

MR. WICKLUND: The accepted methods of compliance and the regulations haven't changed. Some of our assumptions based on recent learnings have changed, and the modeling capabilities have changed, as well.

MR. MURPHY: Mr. Spinney hit on this for -- when he was asked this morning with regards to what has the FAA done in lieu of the two recent events in going forward. And I'd like to ask the same thing from the transport side, from the Part 25 side. Given only these two wide chord fan blade events, how has the FAA evaluated the potential risks to the rest of the in-service fleet, and what is the plan going forward with regards to the inlet and the fan cowl?

MR. WICKLUND: So for the 737 NG and CFM56 engines, as Mr. Spinney explained earlier, the FAA has issued an AD for the engine, which addresses the initiating event. And for the

transport airplane side, we've also identified the inlet separation as a safety concern.

MR. MURPHY: Okay. Thank you very much for that, Mr. Wicklund.

Let me move on here -- sorry -- get my pages around.

Mr. Syberg, you described this morning the purpose of the inlet and the purpose of the fan cowl. And what I would like to do, then, is to get directly into then what are the loads that the fan cowl and the inlet are sized for during a FBO, or fan blade out, event?

MR. SYBERG: Could we please bring up Exhibit 7-B, slide 5? Thank you.

So this illustrates a high-level timeline of the events that occur within a fan blade off event as they were both understood at the time of certification and continue to be understood now. There are a few variants that we have learned in these events that will vary what we have up here, but from the highest extent, at time equals zero, we get the loss of the fan blade. From there, the next 20 milliseconds or about two-hundredths of a second, over the next two revolutions of the engine, you get the point where -- the impact phase where the fan blade hits the fan case, putting a lot of energy into the fan case.

And then there's a ripple effect of like a wave that goes fore and aft and crosses the A-flange and puts an effect of a load into the inlet. Additionally, as discussed earlier by

Mr. Habedank, the blade fragments. It goes into several pieces, and those fragments can move forward and also enter the inlet. So those are two areas of design feature in the impact phase that the inlet is designed for.

The fan cowl, which is not directly attached to the fan case like the inlet is, it doesn't experience that same level of ripple effect that we get from this impact phase. So the fan case isn't as involved in that phase.

As we go through the next phase, the fragmentation causes an airflow disruption in the inlet, which causes the engine to surge. So that surge occurs from about 20 milliseconds to about two-tenths of a second, sending a pressure wave forward through the inlet, and shown there on Figure 2, putting -- imparting a pressure on the inlet inner barrel.

That also commences kind of the shutdown phase of the engine, which commences on what we call the run-down or fan blade out run-down phase, which goes from approximately two-tenths of a second to -- or to 2 seconds. And in that phase, this is where the engine decelerates from its maximum torque or maximum RPM that it's at down to about 10 percent of that RPM or a wind-milling RPM. So there's a significant amount of deceleration torque that's imparted into the engine and the surrounding structure, which would include the inlet, the fan cowl, and all the other propulsion structure. And so in that run-down phase, it ends in about 2 seconds.

So Figure 4 kind of depicts loads, decreasing loads, on the *y*-axis, time on the *x*-axis going about 2 seconds. You see that rapid deceleration in loads.

Following the run-down, from 2 seconds until the airplane lands, it's in a wind-milling state. It can freely rotate based upon the airplane speed. And so the damage that can occur through those scenarios, again, on phase 1 with the impact phase, it's really just the inlet because it's directly attached to the front end of the engine and gets that ripple effect of the case displacements going through. The surge pressure is only applied to the inlet. But then the run-down loads and the wind-milling loads apply both to the inlet and the fan cowl.

MR. MURPHY: Thank you.

During our investigation, we've referred to that ripple effect that you've been -- you just spoke of as the displacement wave. If we go back to the rig test or the certification tests, did that displacement wave cause damage to the inlet or inlet structure?

MR. SYBERG: Yeah, through the test that we supported, you know, again, at that time frame, our analytical capabilities of understanding what the displacement wave was, was not understood from the analysis side. So that's one of the primary reasons we would put inlets on both rig tests and certification tests even though they're not required, is to understand those first few milliseconds and how the interaction between the engine and the

inlet affect the inlet.

And so from the test that we supported, there was damage to the area around the aft bulkhead as a result of that ripple effect or displacement wave.

MR. MURPHY: And that damage was the same as you've seen, then, in Pensacola and Philadelphia?

MR. SYBERG: In those areas, yes. Correct.

MR. MURPHY: In those areas? So it was a direct correlation between what was happening in the test and what happened in the events?

MR. SYBERG: That is correct.

MR. MURPHY: Okay. Thank you.

You gave these timelines up here on top. Could you just give us an estimate of how long you think it was for our event from the FBO to the cabin depressurization?

MR. SYBERG: So the NTSB, we've supported their timeline estimate with the review of the flight data recorder information. And it's the NTSB's estimate as well as Boeing's that the fan cowl fragment that hit the airplane hit it within 3 seconds from blade release.

MR. MURPHY: So within 3 seconds, so we're out to the run-down phase, then? We've come that far out in the timeline that was up earlier?

MR. SYBERG: Yeah. From the --

MR. MURPHY: Just about?

MR. SYBERG: Yeah. Yes.

MR. MURPHY: And then my understanding again is we've also spoken about another portion of this run-down that combined -- when we go into the wind-milling, we referred to it as run-on, and we had a difference -- maybe Mr. Habedank would be better to answer the question -- in the certification world or the certification tests or the rig tests, we came down sharply and never got into this additional run-on phase.

So it'll be a two-part. For Mr. Habedank would be that, you know, what would be the reason between the cert and real life and that run-on phase? And then, to you, Mr. Syberg, would be: Is there potential for more damage to be accumulating during this run-on phase?

MR. HABEDANK: I guess for the timeline for the engine piece of this, you know, on the ground -- let me back up for a second. Let's start with the requirements. The Part 33 requirement to run the test is after you release the blade, then you have to keep your hand off of the throttle for 15 seconds until you can shut down the engine unless the engine shuts down by itself.

On our first certification test, we've talked a few times about the five blades that released because of axial retention. That drove a very short run-down on that engine, for example.

As far as running the engine on the ground versus in the air, for the blade-out event and -- for the blade-out damage and event, really there is no difference between altitude and ground. The

loads and the impact, the blade breakup, the moment, the loads through the engine, are all mechanically based, and they completely dominate any type of aero load on the engine. So there is some small presence, but it's dominated by the mechanical load. The centrifugal load on the blade is the same at 30,000 feet as it is at 3 feet.

MR. MURPHY: Okay. Understood. But it did not -- you know, our event went on for 35 seconds in this run-on phase and -- what I was getting at then, but in at least the cert 2-2 test, and I don't know about the other rigs, and I can't recall the 2-4, was there any run-on? Or was -- for reasons you described, did they all come down fairly quickly?

MR. HABEDANK: They came down pretty quickly, yeah.

MR. MURPHY: Came from power --

MR. HABEDANK: Yeah.

MR. MURPHY: Okay.

MR. HABEDANK: For various reasons.

MR. MURPHY: And then, Mr. Syberg, in the work that you've been doing with UTAS, have you identified any consequences on the structures when we get out into this run-on phase?

MR. SYBERG: Well, what we've understood from the run-on phase, if you compare it to the cert phase, the cert phase, the RPMs ran down to wind-milling within about 2 seconds. Here, they didn't run down until about 30 to 35 seconds. But most importantly, in the 2 to 3 second range, the RPMs are about two

times as large as they would have been on the quicker cert run-downs. And energy is a function of speed squared, so that would be about four times the energy would be going into the system at about 2 to 3 seconds.

MR. MURPHY: There we go. I could just yell. I mean, everybody would hear me, but --

(Laughter.)

MR. MURPHY: All right. So that's during the run-on.

And we talked about this at length in the morning, but Mr. Minabe, could you compare and contrast possibly -- I understand there were more damages than just the doubler, and there was more to the redesign when we went from the initial inlet and the rig test to the 2-2 test. Could you go through all the changes that were made as a result of the test?

MR. MINABE: Sure, sure. Let me utilize the UTAS exhibit, if we can move to slide number 4, please?

MR. MURPHY: UTAS, yes, 7-C.

MR. MINABE: So let me walk through the evolution of the inlet. There were two different production configuration inlets that were used between the Rig 4 test as well as the Engine Cert 2-2 test. This depicts the initial inlet design. This particular configuration did not include a containment doubler. The original requirements that we had received through the SCD from Boeing didn't have any blade fragment containment requirements. So we developed this without the containment doublers shown here.

As was discussed this morning, originally it was determined that -- or originally it was the belief that the containment of the blades would be handled by the engine fan case. That's what's shown here kind of on the lower right, if you will, with that 15 degrees. As a result of the fan blade out test during the Rig 4, we saw that fragments were moving forward into the inlet. At that time it was determined that additional containment provisions would be required within the inlet. At that time, then the SCD was updated by Boeing.

If we move to the next slide, so this is the update to what's called the SCD, or the Specification Control Drawing. This was based off of the Rig 4 test. As Mr. Syberg described this morning, there was coordination between Boeing and CFM relative to the fragment that was traveling into the inlet.

So we had these specific parameters for a fragment traveling or spiraling into the inlet. It was certain dimensions. It was about 2 pounds, was traveling about 600 miles per hour, and traveling along the helix angle of about 15 degrees.

So if you can imagine that blue cylinder there, it represents the inlet. It was defined as a fragment traveling into the inlet at about a 15-degree helix angle. We then sized a containment shield such that it would prevent penetration of the inner barrel, and we also sized the containment shield such that that fragment would not travel forward of the containment shield.

If we move to the next slide, so this is the second

configuration of the inlet. This is the one that includes the containment shield that's shown here in blue. And this is the version that we went into the Certification 2-2 test with. During that test, it was determined that the containment shield as well as the inlet performed its intended function. And at that point in time, there was no further redesign required.

MR. MURPHY: Mr. Minabe, if we go back to the first slide -- one more. Yeah, this one here. Just there was more damage, I believe, as a result of one of the tests that led to the other redesigns that are shown here in the attach flange and at the honeycomb interface and the inner barrel?

MR. MINABE: Yeah, so let me explain. So this is the, again, this is the initial configuration that was used during the Rig 4 test. There was a blade fragment that came forward, and it damaged the inner barrel and then also damaged the outer barrel. There was some additional damage in the inner barrel right around where it says the attach ring -- I'm sorry -- the aft bulkhead interface. There was some additional damage in the inner barrel at that location.

If we move to -- actually, if we move over to slide number 7, please, this actually gives a good compare and contrast with the two different configurations. So on the left is the initial design. On the right is the final production configuration. During the Rig 4 test with the initial design, on the aft bulkhead interface, we saw some damage there on the inner barrel. We then

extended the length of the attach ring forward so it would cover that portion of the inner barrel. So that was taken out of the picture for the next configuration. Then we also added the attached -- I'm sorry -- the containment shield, and then we added the length to the attach ring.

MR. MURPHY: Great. Thank you. I've now gotten into the point where we have the overlap with The Boeing Company and UTAS. So whether Mr. Minabe or Mr. Syberg would like, could you take us through, much like this morning, just briefly the relationship between the two of you and the manufacturing, design and analysis of the inlet and fan cowl?

MR. SYBERG: Ms. Kemner, could you please bring up slide 6 from the Exhibit 7-B?

This provides a high-level outline of how the -- kind of the tri-party collaboration took place over the preliminary design, detail design, and certification. As with any airplane program, the airframer stipulates the requirements for the engine. It's usually in terms of thrust and fuel burn. For the inlet, it's usually in terms of loads and aerodynamic configuration.

So once the parties have their sets of requirements, Boeing typically collaborates both with all the parties to, you know, make sure that they understand what the requirements are, how they will comply with those requirements, and then work through the actual demonstration of developing the parts that will comply with the requirements, and then, finally, supporting the validation and

ensuring that all the requirements are complied with.

Regards to a fan blade out event, the preliminary information that comes from CFM is what we refer to as the forcing function, but what it is, it's the internal engine loads that are developed in those first 2 seconds. And that helps Boeing derive loads for the entire propulsion structure, including the wing attachments, where we include things in our model that aren't in the ground test, which are the air loads. And we also look at different release angles that are not done in the test.

From there, we get a preliminary design. Coming out of the preliminary design phase, we had what we believed to be our production inlet that we supported Rig Test 4 with. We've talked about the results of those tests and the subsequent redesign phase that took place.

And during that phase, you know, CFM provided a lot of information on the fan blade history that they have from earlier tests, plus as well as other versions of their engines that they have out there, where they've had containment doublers on other inlets. And they supported with design data from those to help Boeing and UTAS develop the requirements, and then for UTAS to develop the redesign of the inlet. Then you can see the redesign of the inlet goes and fed up to Cert Test 1, where we went and validated the performance of that redesigned inlet.

And then continuing forward with this chart here, coming out of Cert Test 1, again, the characterization of the engine as it

runs down as well as the fragmentation characterization, that goes into a Boeing model of the test stand itself, where we release the angle at the single angle that is released in the test, and we correlate to the forcing function. By doing so, we have measurements on our model at different locations that are also measured during the test.

And once we get the model to the point where it correlates and predicts well with the test, and then we put that model on a wing where we can apply air loads. We can also release the blades at different clock positions going around. And we also look at left and right wings for different stiffness effects, as well as three different fuel levels within the wing to, again, capture the variability of stiffness in the system, because it's the stiffness of the system that will drive the loads through all the structure.

And it is those loads that are finally deployed down to UTAS for the final certification and qualification documents of the inlet; back up to Boeing for the final cert reports that are then approved by the FAA.

MR. MURPHY: Mr. Syberg, we spoke earlier about the different phases of loading throughout the fan blade out event. Understanding that everything is still preliminary at this point with everything we're working on, how has the analysis progressed in both Philadelphia and Pensacola to date, and where are you with the analysis?

MR. SYBERG: So the analysis, which has been going on now for

a lot of time with a lot of resources, and focusing on the timeline we discussed earlier, where it showed that the parts departed the airplane within 3 seconds, that brings into light that the impact phase and the run-down phase are the primary areas we need to look at.

Within the impact phase, we have evidence of scrape marks within the fan case, of fan blade fragments exiting the engine. But on the inlet side, we were only able to recover, you know, portions of the inlet that remained after landing. So within there, there's a lot of detailed metallurgical work going on the fracture surfaces of that hardware that's been obtained. There's also detailed visual examinations of the hardware to understand where all the failure locations are.

In addition to that, we have the timeline that we're working with. And so where the point of the investigation is now, is we're doing detailed analytical simulations using, you know, our latest model capabilities to try to be able to predict the same failure modes and locations that the observations have shown us and that those failures occur within the timeline that we've estimated with the investigation.

MR. MURPHY: Is your or the industry's -- you can't speak for the industry, but from what has gone on during your career, your time frame, has the understanding of an FBO event as it relates to the design of the inlet and the fan cowl structure changed throughout the years?

MR. SYBERG: The physics of an FBO event have not changed, as I've kind of stipulated up there in the 2 to 3 second time frame, but our capability to assess that impact phase has increased substantially. And so what that really means is, in the preliminary design phase, we're able to inform the design by working with the engine company to understand, what we refer to now, but we didn't then, is this displacement wave that gets caused by that first blade that impacts the case.

So when that energy transmits over the A-flange, we actually have analytical capabilities to understand how the inlet can behave from that, and then also how to inform the design to make sure the design going into those first set of tests has a big state of analysis behind it, which allows us to go into these tests with a higher level of confidence.

We haven't changed our substantiation process by still providing production representative inlets for the rig tests for initial, you know, not just learnings, but now substantiation of our analysis process. But we also include the inlets on the certification tests, as well, for our final validation.

MR. MURPHY: Great. Thank you.

With all the analysis that's gone on to date since the Philadelphia event and prior with the Pensacola, is there any evidence -- knowing that this inlet is not symmetrical, is there any evidence to suggest or support that the clock position of the fan blade out occurrence is playing a role in the differences

between Pensacola and Philadelphia?

MR. SYBERG: Yeah. So that's one of the variables between the two events that are part of the analysis now. We're looking to see and investigate each release angle of the fan blade and the energy that it imparts into the system, how the effects of that could -- basically, we're trying to characterize those effects on the hardware and with the observations that we're getting from that hardware now.

MR. MURPHY: Being investigated, then, and no definitive answers, still all preliminary at the time, but definitely being looked at?

MR. SYBERG: That is correct.

MR. MURPHY: Mr. Minabe, we've heard that blade fragments went forward of the containment doubler. What evidence, material evidence or otherwise, is there to suggest, to support that the blade fragments, other than the marks on the fan case, that are also supporting that conclusion?

MR. MINABE: Okay. If we can pull up the UTAS exhibit and move to slide 3, please?

So this is an overall depiction of the inlet on the far left, and then on the far right is a typical cross-section through that inlet. As we've mentioned, the investigation is still ongoing, so a lot of this work is still preliminary. It's still being investigated. There is some trajectory evidence within the inner barrel of spiraling fragments moving towards the upper location of

the outer barrel. There's penetrations through the outer barrel at about the 10 to 12 o'clock location.

And then we've taken some material samples from the penetrations in the outer barrel. The outer barrel is made out of aluminum, and through our material samples that we've taken in that location, through the penetrations, we've found traces of titanium. So that would likely indicate blade fragment debris or damage. However, as we said, the investigation is still ongoing, and we don't have full party consensus on that at this point in time.

MR. MURPHY: For my knowledge and everybody else, is it intended that forward of the containment doubler that the structure would be capable of containing blade fragment damage?

MR. MINABE: No. As I mentioned previously when I was describing how we developed the containment shield that's shown here in blue, we had sized the length of that containment shield such that fragments should not have traveled forward of the containment shield. Thus, we were not expecting any damage due to blade fragmentation forward of the containment shield.

MR. MURPHY: Okay. And then back to the picture with the helix. We don't necessarily have to bring it back up again, but Mr. Habedank, was that -- or Mr. Minabe, was that -- here we go -- was that fragment -- what's that?

UNIDENTIFIED SPEAKER: It likes me --

MR. MURPHY: Yeah, it likes you.

Was that fragment a tip? That 2 pounds, was that meant to represent the tip or midsection, mid-blade?

MR. HABEDANK: Yeah, that fragment, the 2-pound segment, was the tip fragment that went through. And documented in the regulatory certification documents, we put the weight, trajectory, energy, and direction, which was the 15-degree helix angle, as Mr. Spinney described this morning, in the installation manual.

MR. MURPHY: Great. Thank you.

Mr. Habedank, again, coming back to this morning, we were talking about blade fragments again. And we have, I believe, 10 tests -- 8 or 10 -- I'm trying to remember -- 8 rig and 2 cert?

MR. HABEDANK: Yes, a total of eight rig tests and two certification tests.

MR. MURPHY: Amongst all of those tests in their entirety, were the trajectories, masses, and velocities, directional movement, their behavior the same amongst all 10?

MR. HABEDANK: It was similar. The tip fragment was probably the most consistent piece broke off in a similar manner. It always went forward, all 10 tests. So that was probably the most consistent piece.

The mid-span fragments, as we've talked a couple times here today, sometimes they go forward, sometimes aft. Torben, I, and others have said there were multiple collaboration meetings here between Boeing and the agencies and the airframer. As we were going through the rig testing and primarily right before

certification, we reviewed all of the results collectively, and the mid-span fragments were a topic of discussion.

MR. MURPHY: Great. Thank you.

Mr. Minabe, you have I know -- all the hardware for both the Pensacola and Philadelphia are located at your facility. Can you compare and contrast the similarities and differences between those two inlets and fan cowl structure?

MR. MINABE: Sure. If we can move back to the UTAS exhibit and move to slide 9, please? I'm sorry. If we can go back one slide. Yup. There we go. Thank you.

So this is the laboratory setup within the UTAS facility in Chula Vista, California. The picture on the left represents three different units, if you will. On the left is the Pensacola hardware. In the center is the Philadelphia hardware, which is also blown up in the picture on the right. Again, moving back to the picture on the left, on the far right of that picture, there's actually a brand-new inlet and fan cowl that we use for reference.

So this has really been kind of the centerpiece for the investigation with the parties, at least around the inlet and the fan cowl. This is where we've been taking a lot of the physical evidence. We've been taking a lot of the metallurgical samples from these units. UTAS has been involved with the trajectory analysis through the inlets in both cases. So really the centerpiece of the party investigation at least for the inlet and the fan cowl.

If we can move to the next slide, this gives a little bit of comparison between the Pensacola and the Philadelphia event. On the left is the Pensacola event. The right is the Philadelphia event. The fan cowls in the Pensacola event, they did stay attached, as we had talked about.

We believe a reason for that, one of the reasons for that was that the aft bulkhead on the inlet, as you can see in the upper left -- it's the silver bulkhead, if you will -- stayed in place. The fan cowl, which is the blue portion there in the upper left stayed -- I'll call it tightly wrapped around that aft bulkhead. So we believe that might have been a contributing factor to why the fan cowl stayed attached in Pensacola and not on Philadelphia.

If you move to the picture on the right, that's the Philadelphia unit. We did see the departure of major portions of the inlet as well as the aft bulkhead. We believe that may have contributed to some of the scooping underneath the fan cowl.

What you'll also note is in the two pictures above, in kind of the greenish, dark-greenish color, if you will, that is what we -- that's the containment shield. And in both events, the inlet departed, portions of the inlet departed just forward of that containment shield. So that green cylinder that you see in both pictures, that represents the containment shield. In both cases, the inner barrel of the inlet departed at that location.

If I move down to the next slide, or the next bullet, we talked about the aft bulkhead. We talked about now the blade root

impact. The root impact was different between Pensacola and Philadelphia. We know that the blade root impacted on Pensacola at about the 3:30 location, and the Philadelphia, we believe it impacted about the 6:30 location. As Mr. Syberg was explaining, we're still investigating if that has an impact or not. And those results are still outstanding.

In terms of where the blade tip was arrested, we believe that we may have arrested the tip in Pensacola within the containment shield. Again, this is just preliminary information. We don't have full party consensus on that at this point in time.

Same thing on the Philadelphia event. We believe the blade tip spiraled into the inlet. There is evidence that it may have been captured within the 9:00 splice, but again, that's preliminary information. We're still under investigation if those are really the tips or not.

MR. MURPHY: And just to follow on with that, not to assert or make any assumptions, back to you, Mr. Syberg, everything is still on the table as far as other load phases contributing to the damage and separation of the inlet? There has been no one determination of any of the items that were along the top of your chart that we looked at earlier?

MR. SYBERG: That is correct. We're looking through each phase of an FBO event, trying to understand within each phase and the observations we have here what is, like, a plausible range of scenarios, say, from fan blade fragmentation damage, and looking

to see if any of those could result in some of the plausible failures that we've indicated and within the timeline that it has been estimated.

MR. MURPHY: Great. Thank you, gentlemen.

For right now, that's all I have, and I may follow up if we have time.

HEARING OFFICER ENGLISH: Thanks, Brian. We'll go around the panel.

Mr. Scarfo?

MR. SCARFO: I'd like to get a little clarification on the sizing of the containment shield. It's my impression that the sizing is based on the fragments sliding across the shield and dissipating its energy. Was there anything looked at as far as if blades don't actually perform that sliding action, but actually fly? And if not, is that going to be part of the future analysis for determining whether the containment shield is correctly sized?

MR. MINABE: Is that question for -- who's that question for?

MR. SCARFO: Either or.

MR. SYBERG: So at this point, the containment doubler was sized for what we saw on Rig 4, which was a penetration through the inner barrel and through the outer barrel. The requirement as it was depicted was originally received from CFM as 1.8 pounds at a certain speed and certain trajectory. Boeing increased the size of the fragment to try to account for not just the tip, but maybe some ancillary damage from the mids, as well.

And going through the investigation here, Boeing is looking at a full range of potential fragment trajectories and the potential impacts on the inlet. Now, whether you're sliding along the doubler or trying to penetrate through, those are all trajectory angles that are being assessed now.

MR. SCARFO: Okay. Thank you.

This question is for Mr. Wicklund. Earlier this morning, Mr. Spinney had provided us some information on what the FAA's position is on a Part 33 pass/fail. Since you had mentioned that both a test of the inlet or by analysis it's acceptable, what is the FAA's position or what is your pass/fail criteria for the inlet?

MR. WICKLUND: So for the inlet, as I mentioned earlier, the requirement is that no single failure of the propulsion system can jeopardize continued safe flight and landing. Considering that a fan blade out event would be a single failure and considering that the size and mass of the inlet, the pass/fail criteria would be to retain the inlet in a fan blade out event.

MR. SCARFO: So in both the Pensacola and the Philly event -- and maybe this is where I need a little bit of clarification -- we did lose the inlet, but we didn't lose the entire inlet. So I'm kind of trying to understand if there's a delineation that you can lose a portion of it, you can't lose any of it? Is there a way to kind of gauge? Because, like I said, we didn't lose the entire inlet, but we lost --

MR. WICKLUND: Right.

MR. SCARFO: -- a good portion of it.

MR. WICKLUND: So during certification, you would -- we would expect the airframe manufacturer to show that anything that departed the engine during a fan blade out event wouldn't, say, impact the wing or the empennage in a way -- essentially, because of the size, a full inlet impacting the wing or the empennage, would not be acceptable because it would be very difficult to show that that wouldn't be -- that wouldn't jeopardize continued safe flight and landing.

As you get smaller, there may be other ways to look at it, but it would have to be -- they'd have to demonstrate that whatever they lost wouldn't jeopardize the continued safe flight and landing.

MR. SCARFO: Okay. Thank you. That's all.

HEARING OFFICER ENGLISH: All right. I'd just like to clarify a little bit, follow-up on what Mr. Scarfo asked of Mr. Syberg.

You mentioned the fragments that departed or were found in certification and we think were relatively similar in the Philadelphia event, either surfing or making sort of a penetration to the inner barrel. At the time of the certification test in the mid-'90s, was that geometry, that detail of trajectory, part of the information that was shared between the engine manufacturer and Boeing or was this more looked at as just sort of a point of

trajectory?

MR. SYBERG: Based on the information that we obtained from CFM, which was after a combination of several tests that they had run, plus tests that they had run on some of their previous engine installations for similar engines, the trajectory path of kind of a sliding over the A-flange into the inner barrel was consistent with what they'd seen on some of those -- on all of those programs. And so we use the energy as defined by them.

Now, you're using the term geometry of the blade. The geometry of the blade was not necessarily defined. It was more in the energy, and then in the substantiation method, geometry wouldn't play a factor in it. It was really the energy that we had to contain that was part of the design process.

HEARING OFFICER ENGLISH: Did you have a follow-up?

MR. MURPHY: I wanted to follow-up with Mr. Syberg.

We talked about the analysis that has changed between the past and today. So on your new programs, I think there's maybe three new engine programs going on. What is different with those programs today? As you mentioned, you said before you knew the displacement wave was there, but you couldn't quantify it. And so you just accounted for the damage when you went forward with your fail safe analysis.

So with regards to what you're capable of today in these new programs, can you compare and contrast between this cert on the NG and what you're able to do today, and working with the engine

manufacturer on that?

MR. SYBERG: Yeah. So in today's programs, when we start collaborating and we've determined the engine manufacturer or engine manufacturers for a given program and the definition of the requirements, one of the requirements is working together to understand this displacement wave. We work with them to get preliminary information based on their best practices, where they believe the size of the fan blades are going, where they believe the material systems are going for their fan case for the containment process. And over time, fan blade material systems, fan case material systems, are migrating to, you know, higher-capable materials. And all of that behavior, as far as the displacement wave is concerned, varies from program to program. And so that collaboration has to start early.

And so the design of both the engine side, which is the fan blades and the fan case, and the inlet, they kind of evolve together now. There's much more of an alignment with when you get to those first set of tests, the results are much more expected. If you look at the mid-'90s and the history, at least within Boeing's history of working with engine companies on these tests, we follow the same process of providing an inlet because of the interaction between those two structures is highly dynamic and highly reliant on the constituent designs, the material systems used. And it's everything -- every -- each time, it's a unique situation.

And so now, and comparing with those tests, we had a lot of tests failures from program to program. And our best practices were to get on those tests to understand that interaction. The biggest difference today is going into those tests, we come out of those tests with very few redesigns because the analysis tools bringing us into those tests inform the design much more sooner.

MR. MURPHY: So with today's capability, going into the tests, you're -- it's not as much of a wait and see what happens; you already have a very strong idea of the outcome?

MR. SYBERG: That is correct.

MR. MURPHY: All right. Great. Thank you.

HEARING OFFICER ENGLISH: I think that does it for the Tech Panel's time.

Member Dinh-Zarr?

CHAIRMAN DINH-ZARR: Thank you, Mr. English.

I think it's time for a break. We'll take a 14-minute break. We'll be back at 1:55.

(Off the record at 1:40 p.m.)

(On the record at 1:55 p.m.)

CHAIRMAN DINH-ZARR: Ladies and gentlemen, now we'll move to the part of this hearing where the parties have time to question the witnesses. I think the Technical Panel is through for the time being. We'll give them another opportunity for follow-ups after all the other questions.

So we'll start in the same order we started before, and we'll

start, and please let me know if you have questions.

The Boeing Company?

Looks like we are having problems with our microphones.

MR. McINTOSH: Thank you, Madam Chairman. The Boeing Company has no questions at this time.

CHAIRMAN DINH-ZARR: Thank you, Mr. McIntosh.

Federal Aviation Administration?

MR. GUZZETTI: There we go. Thank you, Madam Chairman. I do have just a few questions.

If you could pull up Exhibit 7-D, the very last slide -- I think it's slide 17 -- I'd like to ask Mr. Wicklund a question or two.

And basically, while that's being pulled up, Mr. Wicklund, similar question to what I asked Mr. Spinney in the morning regarding the engine. Could you just kind of summarize where the FAA was and their actions with regard to the inlet after the Pensacola accident and then continuing on through to the Philadelphia event?

MR. WICKLUND: Certainly. So following the Pensacola event, the FAA focused our attention on addressing the initiating issue, which was the engine and proceeded with the Notice of Proposed Rulemaking to implement the inspections on the engine. We also reviewed the inlet on the Pensacola event with Boeing carefully.

And based on the amount of fan blade that traveled forward, we determined that we agreed with Boeing that it did seem -- we

had not seen that type of failure before in all the testing that had been done even with CFM and did not expect -- we thought it was an anomaly. We did not close the review and agreed to just continue to monitor the fleet at that point.

MR. GUZZETTI: And then when Philadelphia happened?

MR. WICKLUND: So when the Philadelphia event happened, we realized in coordination with our engine experts that indeed the Pensacola event was not an anomaly, and that's when we took immediate action with the engine AD. And we continued to review the engine inlet to this point, as well.

MR. GUZZETTI: Okay. Thank you.

Quick question for Mr. Syberg. You indicated that the Pensacola event, the inlet, there wasn't as much of the inlet as there was from the Philadelphia event, because, apparently, it was not recovered. Presumably, the bulk of the inlet from Pensacola was not recovered because it was likely over the Gulf of Mexico. Does that offer an additional challenge --

MR. SYBERG: So the observations from both events have indicated that a large portion of both the Pensacola and Philadelphia inlets departed. As far as the amount of total inlet structure that was recovered from both events, yes, that has made it difficult to understand all the fractured surfaces that are not there to investigate to understand what were some of the causes of those failures.

MR. GUZZETTI: Okay. And speaking of challenges, you

indicated that, you know, the physics have not changed, but the capability to model an event like this has changed over the past 10, 15, 20 years. How does that -- does it take less time to conduct analysis like this because of all the modeling than it would have 20 years ago?

MR. SYBERG: It enhances our capability to be able to understand the physics of the impact phase, so both the ripple effect of the displacement wave crossing across the fan -- sorry -- against the A-flange, so it's helped us in that understanding, relying on predictions that are validated by test, opposed to just waiting until you get the empirical data from the test.

MR. GUZZETTI: Okay. But still, it isn't like you can just take an event like this and in 30 minutes on a laptop figure out every impact angle, every variable? It takes a lot of time regardless of the modeling, does it not?

MR. SYBERG: Yeah. That is correct. It is an extremely complicated model. For the aspects of this investigation, we're actually taking the model beyond where we have taken it before even with the last 20 years of enhancements. And so, from there, we have a lot of correlating activity to do so we can trust the information that we're getting from those analyses. And that is taking some time.

MR. GUZZETTI: Okay. Thank you.

That's all the questions I have, Madam Chairman.

CHAIRMAN DINH-ZARR: Thank you, Mr. Guzzetti.

Southwest Airlines?

MS. CARROLL: Thank you, Madam Chairman. Southwest Airlines has no questions at this time.

CHAIRMAN DINH-ZARR: Thank you, Ms. Carroll.

CFM International?

MR. JUENGER: Thank you, Madam Chairman. We have one question.

Mr. Habedank, recognizing the technical investigation is still ongoing, has the investigative team identified other potential sources of titanium other than fan blades that were liberated in the event that could result in trace amounts of titanium on the fracture surfaces of the inlet?

MR. HABEDANK: Yes. It's my understanding that there are other sources of titanium in the inlet.

MR. JUENGER: Thank you.

CHAIRMAN DINH-ZARR: Thank you, Mr. Juenger.

United Technologies Aerospace Systems?

MR. ANDERSON: Madam Chairman, good afternoon. I think the questions to date have covered everything. We have no questions.

CHAIRMAN DINH-ZARR: Thank you, Mr. Anderson.

I now will turn to the Board of Inquiry. Ready, gentlemen?

I'd like to start with a explanatory question, a fairly basic one. I think we've talked about the inlet, why the impacts of the inlet onto the aircraft is important. But I know that Mr. Syberg

-- you don't have to answer this; anyone can answer this -- about the aerodynamics of the inlet. Could you explain so that the audience, perhaps passengers who were on this flight, why an inlet is important, the drag, very briefly just so that general public can understand? Just wait a moment. Yup.

MR. SYBERG: For an engine to operate and perform at its maximum capability, it has to have smooth, uninterrupted airflow. And as an airplane is not always flying straight nor are the winds always approaching the engine straight on, the contour of the inlet is highly important to be able to create a smooth aerodynamic flow into the engine without any turbulence. When you get turbulence, you start getting effects on fan blades, things like fan blade flutter, which increase the stresses of that. So the inlet is extremely important for the performance of the engine itself.

CHAIRMAN DINH-ZARR: Thank you, Mr. Syberg.

Now, I have a question about the testing. And this is for the entire panel, but perhaps mostly maybe Mr. Habedank. How do you account for the real-world situation when you're testing? Because testing is taking place at ground level, things like altitude or since you're testing at the maximum speed, how do you account for a lower speed action? I mean, is there modeling done? I mean, how do you account for all of these different real-world effects?

MR. HABEDANK: Yeah, so relative to ground versus in the air,

as I described a little bit earlier in the session, the mechanical loads during a blade-out are at maximum RPM, plus a small amount of the engine. We have to run it at that max speed, which is also known as redline. And as I mentioned, we add a little bit of margin to that to assure that we don't violate the criteria.

So on the ground, there are -- if you have the engine hanging 10 feet in the air on a stand like we would normally do that, you've got some, obviously, pumping air through the engine. But the mechanical loads from the speed and then the release and all those impact waves that Torben was -- Mr. Syberg was talking about, that dominates those loads. The relatively small aero loads on the blade do not -- does not affect that blade-out event. So we make that assertion from all the -- just comparing all of those loads in the ground condition versus in the air.

The one thing we obviously can't account for is after that event, you know, depending on what kind of damage you get with the fact that you're just running at -- you're still running the airplane at a high speed, you get a ram effect into the engine, and that will keep the fan running a little -- that run-on will be a little bit slower.

CHAIRMAN DINH-ZARR: So the altitude isn't really a problem, testing whether it's at ground level or altitude. What about the speed of the testing? Is there a way to -- or is it important to account for lower-speed fan blade outs?

MR. HABEDANK: Okay. I just want to make sure I understand

your question, Madam Chairman. You're asking specifically does -- is there a worst case -- when you're talking speed, you mean revolution -- the spinning speed?

CHAIRMAN DINH-ZARR: Right.

MR. HABEDANK: Is that correct?

CHAIRMAN DINH-ZARR: Right.

MR. HABEDANK: Okay. Yeah, the worst case for the engine is absolutely at maximum speed. That's where the energy will be the highest. When you're at the maximum RPM and plus some, that's the way to get the highest energy into the system and test the system to assure that it can maintain the load or it can survive the event with all the criteria we described earlier with not coming off the mounts and penetration, no fire, and able to safely shut down the engine.

CHAIRMAN DINH-ZARR: Okay. So there aren't any situations where there would be any other types of results when it's not at max speed? I mean, that is -- you're saying that is the worst case scenario, but there are no other types of actions that could come that would be not predicted by this worst case scenario, is that correct?

MR. HABEDANK: That's correct. If the event happens at lower speed, then whatever damage or release impact, all of those loads and results of the release will just be much less than at max speed.

CHAIRMAN DINH-ZARR: Thank you, Mr. Habedank.

Since I have just a few minutes left, I wanted to ask further about -- and this should be for Boeing and CFM -- about the communication and coordination between the engine and the airframe manufacturer during the development of the engine and structure that it's going to be located in.

And I know you reviewed some of this through your slides, as well, but could you clarify for me what exactly are the types of test result data that the engine manufacturer provides to the airframe manufacturer regarding specifically the potential impacts of a fan blade failure?

MR. SYBERG: Okay. Referring back to our earlier discussion, there are multiple phases, the first phase being the impact phase. From that phase, we get levels of data, as far as the impact energy from the blade into the case, which that goes into the modeling that Boeing performs to understand that ripple effect of that load into the inlet structure, because the inlet is bolted directly to the fan case. And when the fan case deforms, the inlet will deform with that. So that's instrumentation that's usually developed through high-speed video.

Additionally, there are, you know, loads/measurements that are associated with it at that A-flange that we get. So that's loads and deflections.

The high-speed film as well as a review of the hardware after the test gives us an understanding of the fan blade fragmentation, any fragment damage that come forward of the inlet. So that's

more in the observations.

Then the loads that Mr. Habedank was talking about, as far as the mechanics of the engine really running down or shutting down, those were very high loads, extremely higher than any air loads you would receive. So air loads don't really partake on those first couple of minutes we get -- or first couple of seconds.

Boeing receives the characterization of that run-down in terms of internal engine loads in torque and lateral and vertical accelerations. And that data is obtained through instrumentation. We call them strain gauges or loads measurements data that are located at different places both on the engine itself, but on some of the Boeing propulsion structure like the engine mounts. And we have other locations where we get loads data from the test.

And going back to one of the other presentations that showed our mathematical model of an actual test stand and an actual engine with all of our hardware, we will then run the exact same release angle at the exact same RPM that was performed in the test and correlate the model at those locations where we've measured the loads through these loads measurement devices.

And once we have that correlated, we then move that model onto a wing and now model that on a left and a right wing, three different fuel levels, it'll give you three different stiffnesses of the wing, also with the different release angles, around-the-clock positions. It ends up being about 48 runs instead of just the one engine run.

So while the internal engine mechanical behavior in 2 seconds is irrelevant if it's a test stand or an air situation, that doesn't change. Those physics don't change. But then we add all the associated air loads and other release angles. And for things external to the engine like CFM's engine mounts, they will receive those loads, as well. So while they show their engine mounts capable on that one test, they also show their mounts capable to all the loads that we give them that we size our mounts for, as well.

CHAIRMAN DINH-ZARR: Thank you, Mr. Syberg.

And I'm afraid I've gone over my time. I'm going to turn it over to Mr. Budinski.

MR. BUDINSKI: Good afternoon. My first question I think will be directed at Boeing, Mr. Syberg, but others may chime in. I'll follow on to Chairman Dinh-Zarr's question. Are there concerns about the fan cowling and inlet failures and associated drag on fuel reserves for ETOPS flights? Just wondering about that.

MR. SYBERG: So the variables that are in this investigation include what are the effects to the airplane at an airplane level when you have parts departing the airplane. And the aspects that you just spoke of there are part of the variables that we look at. We look at the associated potential hazards of parts departing the airplane, their impacts both to the structure, but also the performance of the airplane.

MR. BUDINSKI: Anybody else chime in? No?

My next question -- and again, I'm going to put this out to all the folks on the Panel. You know, I understand, and I wanted to try to get this into more tangible terms for the average person, but this fan case distorts during an FBO test? It actually develops, like, a wave that flows around it. So there's, like, essentially, sort of a wave or a lump that flows around it, and I'm not sure that that's necessarily recognized by everyone. But as that happens, how does this distortion affect the mounting of the inlet and the fan cowling, and so forth? And how is that exactly tested to understand that distortion?

MR. SYBERG: So if I understand the question, how are the effects of the distortion from the fan case addressed --

MR. BUDINSKI: Yeah.

MR. SYBERG: -- through the inlet design and mounting of the inlet?

MR. BUDINSKI: How do you account for all of that for securement of the nacelle structure through testing and certification, and so forth? How is that all done?

MR. SYBERG: Okay. So if we look at the design aspects, there are 24 mounting bolts that go around the circumference that attach the inlet to the engine. And instead of just having a bolt with a head and a nut, we actually have what we term as an energy absorption spacer. And so as a particular bolt, the bolt that's reaching the highest tensile load, before it reaches the

capability of the bolt, you'll reach the crushable capability of the spacer, thus relieving the load from that bolt, leaving it intact, and driving the load to the subsequent two bolts. And that goes into a domino effect, protecting the tensile load of the bolts from being overloaded and allowing the load to distribute around the periphery.

So that's from a design perspective, and that's been kind of a best practice that Boeing has used on multiple models to address that specific concern. Again, as we've discussed, putting these inlets and getting the empirical test data on rig tests and certification tests, the observations from those tests, whether it be in the state of the hardware after the test or the high-speed films that we look frame-by-frame to see how the structure is behaving, that's a way we use the test data to validate either the analysis or the design.

And then following through to this, you know, run-down phase, where you get the high vibratory loads as the engine is spooling down, we correlate that directly to test so our analytical predictions match what was tested. And then we put that on the wing models and look at all the different fuel stiffness or, you know, stiffness behaviors from the different wings and the different fuel scenarios and the different release angles to completely envelope the entire structural load distribution that could occur from a fan blade out event and make sure through analysis that all of the structural components, not just the

inlet, but all of them, can sustain those loads.

MR. BUDINSKI: Thank you.

Well, obviously, you know, we've had some failures in real life, so I'm wondering whether that has to do with the radial location of the blade release relative to the engine itself, and then the securement of the nacelle, and all that, the nacelle structure and the inlet. And you know, if a fan blade out was tested at the 6 o'clock position or 3 o'clock position, how would that change, because, obviously, it seems like things are getting stressed in ways that the certification test didn't really fully anticipate.

MR. SYBERG: I apologize. Could you reframe what the question is there?

MR. BUDINSKI: So the -- my microphone -- it's working now. So my question is would it be advantageous to test different radial locations rather than -- can you hear me?

MR. DELISI: Yeah. One, two.

CHAIRMAN DINH-ZARR: Try again.

MR. BUDINSKI: So the question would be that would it be advantageous to test a radial position other than 12 o'clock position to assess the securement of all the nacelle structure and inlet structure, and maybe be loading the latches and the latch areas in a different way than they are at the 12 o'clock position? And so has that ever been considered or have you done that? Or how would you account for the pressure wave moving up -- the

distortion wave moving around if it wasn't at the 12 o'clock position, if it was at another position?

MR. SYBERG: So these tests that are run are either rig tests or certification tests for the engine company. The engine company works with their regulatory authorities to understand exactly how they're going to run that test, and that is a discussion between the engine companies and the engine certification organization.

Boeing partakes in those tests, but it's the engine company working with the regulators to understand what is worst case for the engine, because it is a containment test to make sure that the engine can contain that blade and that a fire doesn't exist, they can shut down the engine, and that the mounts are capable of sustaining those loads.

It is my understanding that for the CFM56-7B certification test, the 12 o'clock release position was chosen to maximize the loads on the engine mounts, as this is an engine test. It is for that reason that Boeing puts into our models all the different release angles, and in doing so, the forcing function that we referred to, which includes the actual impact load in terms of pounds that are applied directly to the fan case, we revolve that around the different clock positions in our modeling to understand those effects of that ripple effect or load effect that goes into the fan case.

We don't rely solely on the single test to do that. We only do that to correlate our analysis so we have an accurate set of

measurements which to predict the loads, and then we rotate around that at all the clock positions to account for that variability.

MR. BUDINSKI: Thank you. Do any of the other Panel members want to contribute to that? No? Yes?

MR. HABEDANK: I was just going to add that I thought Mr. Syberg summarized that very well. He was accurate in the assessment of the engine test and requirements.

MR. BUDINSKI: Okay. Thank you.

That's all the questions I have at the moment.

CHAIRMAN DINH-ZARR: Thank you, Mr. Budinski. Sorry for the technical issues.

Mr. DeLisi?

MR. DELISI: Thank you.

Mr. Wicklund, you mentioned earlier that there is not a requirement to have a production inlet on the engine when it's undergoing the fan blade off test. If a manufacturer chose to put a production inlet on for a ground test and it was damaged to the extent that we saw in the Philadelphia accident, would that be a test failure?

MR. WICKLUND: Most likely, that would be determined to be a test failure, yes, that would require some sort of corrective action or corrective design during certification, yes.

MR. DELISI: Mr. Habedank, the material that makes up the fan containment ring, what -- I've heard of Kevlar being used in an application like that. What type of material is used in this

engine?

MR. HABEDANK: The material of the 7B fan case is aluminum. There is no Kevlar present on the 7B.

MR. DELISI: Is the aluminum a pliable material?

MR. HABEDANK: Can you specify exactly what you mean by pliable?

MR. DELISI: Well, when a fan blade off event comes out, approximately how far can you displace that aluminum?

MR. HABEDANK: I'm not sure how to quantify that, to be honest. I mean, it's accounted for in all of the tests. It's representative -- it's typical aluminum with an elongation, if I remember right.

MR. DELISI: Could it bow out an inch, 2 inches, 6 inches, 9 inches?

MR. HABEDANK: We have seen on video it bulges out an inch or more.

MR. DELISI: So, and then incorporating that engine into a nacelle, wouldn't you need a void space an inch or more all the way around the engine so that a fan blade off at any angle could create that displacement without damaging the structure?

MR. HABEDANK: That is part of our assessment leading up into the test and how we place the components that are bolted onto the fan case. That's a big part of the test, as well, is, as you run through that test, you can't be releasing any of the other components that are bolted to it. It's all part of the overall

engine architecture.

MR. DELISI: Mr. Minabe, you used the term earlier a couple of times that there wasn't full party consensus on something. Could you remind us what that was?

MR. MINABE: Sure. So the investigation is still ongoing, and we're -- all parties are evaluating the evidence and the physical evidence and the trajectory evidence, as well as the metallurgical evidence. We haven't come to a conclusion yet on all the findings, and so that's what I'm referring to. We just don't have full consensus on all the -- the combination of all these findings, what it really means.

MR. DELISI: Sure. That sounds like the analysis that will be necessary to complete the investigation, but from a fact-finding basis, can't all the parties get together and look at those mock-ups that you've got and spend a day, two, three talking it all over till you all agree on what it is that we're seeing?

MR. MINABE: Yeah, we've been, we've been -- it's very complex, first of all. There's so much data. The hardware is in such a shape that it takes a lot of investigation in terms of understanding what you're looking at. So there's things that you might first look at and think of it's one thing. And then if you come back and look at it again, you can think of it as a different way. So it just takes an enormous amount of reviewing of the data and just making sure we've got it right. And it just takes a long time to do that.

MR. DELISI: So the accident was 6 months or more ago. How much more time do we need to get there?

MR. MINABE: Well, we're still, as I mentioned, we're still in the investigation. There's still a lot more data, believe it or not, to look at. I believe there's going to be additional meetings between the parties to come to that consensus. I can't really speculate in terms of how much time it's going to take. It might take a couple more months, but that would just be speculation on my part.

MR. DELISI: Okay. Thanks.

We talked a little bit about air loads and one of the differences from a ground test to the inflight events that we've seen being air loads. There was an answer earlier about the effect that air loads had on the fan blade, but now I want to talk about the effect that air loads might have on inlet structure.

So the type of damage that we might see during a ground test to inlet structure, isn't that going to be exacerbated now when there's air load up against that damaged structural material?

MR. MINABE: That could be the case. So, you know, the various angles of attack, the air speeds, they're not replicated on the ground tests. So there are additional aero loads during the event. We just haven't quantified in terms of the magnitude of those aero loads at this point in time.

MR. DELISI: Mr. Wicklund, I think you used the term earlier that a fan blade out event, to be successful, had to not

jeopardize safe flight? Is that a fair assessment of the criteria?

MR. WICKLUND: That is correct.

MR. DELISI: But we're seeing in the two Southwest events that there is a jeopardization of safe flight when a fan blade out happens. Is that causing any rethought about the technique that's used to demonstrate the safety of a fan blade out event?

MR. WICKLUND: Well, I think that mainly what we're talking about is making sure that when a fan blade out occurs, that the cascading failure doesn't jeopardize continuous safe flight and landing. And the expectation, when we talk about the inlet, is that it's retained. So, to answer your question, no, there's really no reassessment of that approach or those criteria.

MR. DELISI: But we are seeing inflight on the Southwest events, on a Delta event in Honolulu, that inlet retention is not assured even after a successful certification test. So isn't that a good opportunity to rethink what we're doing on the ground and how well it simulates that failure in flight?

MR. WICKLUND: I think that we have assessed the events that you're talking about, and we have determined that the corrective action -- that it is a safety issue.

MR. DELISI: Yeah. And I guess the safety is twofold. One, we don't want fan blades to come off, but if they do, we have done a certification program to assure a level of continued safe flight for the airplane. It's that second piece that's being called into

question now. And yes, it would be great to ensure that we don't have additional fan blade failures. We heard this morning that eight additional fan blades have been pulled from service for crack indications since the Philadelphia event. But don't we need to rethink the second half of that, about whether the fan blade out ground test gives us that extra level of safety to protect the airframe when a fan blade out event does happen?

MR. WICKLUND: Certainly, we do assume that a fan blade -- for a certification, we assume that we will encounter fan blade out events. As you've mentioned, they do occur. So in evaluating the cascading failures, we want to make sure that those don't jeopardize safety. And as you mentioned, the inlet, we've had a couple of inlets depart the airplane, and that would not meet the certification requirements.

MR. DELISI: Very good. Thank you.

MR. WICKLUND: Thank you.

CHAIRMAN DINH-ZARR: Thank you, Mr. DeLisi.

And I'm going to allow the Technical Panel additional time for questions. Mr. English?

HEARING OFFICER ENGLISH: We'll just pass it to Brian Murphy. You have some clarification questions?

MR. MURPHY: Going back to Member Dinh-Zarr's question, Mr. Habedank, you expressed that as far as the engine is concerned, that red-line plus is very important for the test because it is a Part 33 test. It is a containment test.

My question, then, is directed at Mr. Syberg to say: Are we learning from this event and going forward in understanding that maybe the lower RPMs and the ability of the case structure, whether it be composite or it be aluminum or titanium or unobtainium, in absorbing or capturing the blade when it's released, and when we're coming out at these lower RPMs, maybe we've got an unknown, as far as fragments not being contained in the case and making their way to the inlet?

MR. SYBERG: So part of this investigation, Mr. Murphy, is exactly to try to understand that the impact that could -- sorry -- the impact that these fan blade fragments could potentially have on inlet at different variables that aren't tested, right? And so this investigation is still ongoing. We're investigating a wide range of potential scenarios as associated with these blade fragmentations and the inlet's ability to sustain damage and under the varying loads that occur during that time frame. So it's absolutely part of the intent of this investigation to better understand that.

MR. MURPHY: And I believe, Mr. Habedank, too, also that even at CFM, analytically, you've begun to address the blade fragment movement even within the case and with the models that Boeing has provided you to look at these lower speeds and what you're also seeing?

MR. HABEDANK: Yes, that's right. Working with that collaboration through the investigative team will -- we're

developing those models, and we'll be able to -- with that additional computational power and ability, we'll be able to look at a lot of different scenarios, including speed.

MR. MURPHY: Great. That's it for me.

Pierre, or Mr. Scarfo?

HEARING OFFICER ENGLISH: No?

I'd just like to go back to, you know, follow up a little bit more on what Brian is talking about. I'll start with Mark Habedank. Just to explain a little bit more on where we are going, just the process of our investigation right now, can you walk through just that sequence of what you're looking at where the fragments -- we've talked about fragments moving through fan case and then the containment doubler, and so on. What types of factors are you looking at with this further modeling that you're discussing?

MR. HABEDANK: Yeah, I think this is probably a question that both Mr. Syberg and I should both probably comment on.

HEARING OFFICER ENGLISH: Right.

MR. HABEDANK: From our perspective, Mr. English, you know, the fact that we have the information on all of the blade fragmentation, as has been highlighted today, we've got some evidence on the event engine that shows angles of, you know, the helix angle of the trajectories coming through, we know the other trajectories, I think that's a great start for the analysis. A big part of the analysis, I think, is really going to be -- and I

assume Mr. Syberg agrees with this -- a big part of this is going to be trying to separate out what is damage from fragmentation on the inlet and what is resulting failure, if you will. And I put those in two different categories. I think that's what the team is really challenged with right now, to try to separate out, you know, this piece is broken; well, was it penetrated or did it fail because of the loading? And I think that's where the complexity and challenge that Mr. Minabe was speaking of earlier.

Mr. Syberg, if you've got additional comments?

MR. SYBERG: Because we weren't able to recover 100 percent of the hardware of the inlet, we've had to make some assumptions now as what are some of the plausible arenas or scenarios that could have occurred as the fan blade fragments departed the engine. And so instead of just waiting until we have all the metallurgical work done, we're trying to look at ranges of damage and see if any of those ranges could, when associated with a follow-on run-down or run-on loads, the association of those loads with a damaged inlet, where there is -- I'll call it a prediction with our correlated tools that we have parts departing the airplane.

HEARING OFFICER ENGLISH: Very good. Thanks. So just to give a little clarity to the public, when you are running these scenarios, these type of models, can you give us an estimate that, you know, this is -- I think someone mentioned it before -- this is not something that runs on your laptop in 30 minutes, correct?

MR. SYBERG: Correct. These are highly complex models. For these mathematical predictions, we have to put a lot of variables and parameters in there. When we set up a single run to assess a specific scenario, that model runs anywhere from 12 to 14 hours. So we like to set those up at the end of a working day, run it overnight, look at the results the next day, and see if they're believable, see if they correlate. And we're continuing to work this through until we have some plausible scenarios that we can understand and have confidence in.

HEARING OFFICER ENGLISH: Very good. Thank you, sir.

And I think that's a nice wrap for us at the Technical Panel. It gives you an indication of some of the work that we have as the investigative team and the parties to go forward. That's the end of the questions for the Tech Panel, ma'am.

CHAIRMAN DINH-ZARR: Thank you, Mr. English. Thanks to you and the entire Tech Panel for your very good questions.

And thank you also to my fellow Board of Inquiry panel members for your participation and useful questions.

All of the witnesses have now testified, so this portion of the NTSB's investigation into the April 17th, 2018, tragedy near Philadelphia is concluded.

The record will, however, remain open for additional materials requested if needed. And the transcript of the hearing and all of the materials entered into the record will become part of the public docket, along with any other records of the

investigation.

The archive of this hearing webcast will remain on the NTSB website for approximately 90 days. From the evidence collected in this hearing and from the investigation as a whole, the NTSB will determine the probable cause of this accident and make any recommendations necessary to prevent similar accidents. The final report will take several months to complete. However, safety recommendations may be made at any time we deem necessary.

So on behalf of the NTSB, I'd like to thank the parties in this proceeding for their cooperation not only during the proceeding, but throughout the entire investigation of this accident. And also, on behalf of the Board of Inquiry and the Technical Panel, I want to express our appreciation to the witnesses who provided testimony.

We have covered a great deal of technical information today that will be highly useful in our investigation. But that doesn't mean we've forgotten why we are really here. Our hearts go out to everyone who was affected by that tragic morning near Philadelphia especially the family members of the passenger who lost her life. Rest assured that our commitment remains steadfast at the NTSB, our commitment to learn from this accident so that we can prevent it from happening again.

Thank you. And this hearing is adjourned.

(Whereupon, at 2:38 p.m., the hearing in the above-entitled matter was adjourned.)

CERTIFICATE

This is to certify that the attached proceeding before the

NATIONAL TRANSPORTATION SAFETY BOARD

IN THE MATTER OF:	INVESTIGATION OF THE ACCIDENT INVOLVING SOUTHWEST AIRLINES 1380, BOEING 737-700 WITH CFM56-7B ENGINES NEAR PHILADELPHIA, PA, ON APRIL 17, 2018
ACCIDENT NO.:	DCA18MA142
PLACE:	Washington, D.C.
DATE:	November 14, 2018

was held according to the record, and that this is the original, complete, true and accurate transcript which has been compared to the recording accomplished at the hearing.

Timothy Atkinson, Jr.
Official Reporter