AI2010-2

AIRCRAFT SERIOUS INCIDENT INVESTIGATION REPORT

JAPAN AIR COMMUTER

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February 26, 2010

Japan Transport Safety Board

The investigation for this report was conducted by the Japan Transport Safety Board, JTSB, about the aircraft serious incident of Japan Air Commuter, Bombardier DHC-8-402 registration JA848C in accordance with the act for the Establishment of the Japan Transport Safety Board and Annex 13 to the Convention on the International Civil Aviation for the purpose of determining causes of the aircraft serious incident and contributing to the prevention of accidents/incidents and not for the purpose of blaming responsibility of the serious incident.

This English version of this report has been published and translated by the JTSB to make its reading easier for English speaking people who are not familiar with Japanese. Although efforts are made to translate as accurately as possible, only the Japanese version is authentic. If there is any difference in the meaning of the texts between the Japanese and English versions, the text in the Japanese version prevails.

Norihiro Goto,
Chairman,
Japan Transport Safety Board

AIRCRAFT SERIOUS INCIDENT INVESTIGATION REPORT

JAPAN AIR COMMUTER CO., LTD.

BOMBARDIER DHC-8-402, JA848C

ON RUNWAY A AT OSAKA INTERNATIONAL AIRPORT, JAPAN

AT 16:27 JST, AUGUST 12, 2008

January 22, 2010

Adopted by the Japan Transport Safety Board (Aircraft Sub-committee)

Chairman	Norihiro Goto
Member	Yukio Kusuki
Member	Shinsuke Endo
Member	Noboru Toyooka
Member	Yuki Shuto
Member	Akiko Matsuo

The following acronyms and abbreviations are used in this report.

AMM	: Aircraft Maintenance Manual
AOM	: Airplane Operating Manual
BSI	: Borescope Inspection
CVR	: Cockpit Voice Recorder
dITT	: delta ITT
dNH	: delta NH
dNL	: delta NL
dWf	: delta Wf
DFDR	: Digital Flight Data Recorder
ECTM	: Engine Condition Trend Monitoring
EMU	: Engine Monitoring Unit
ENG	: Engine
FADEC	: Full Authority Digital Engine Control
FIM	: Fault Isolation Manual
HPT	: High Pressure Turbine
HSI	: Hot Section Inspection
ITT	: Inter-Turbine Temperature or Indicated Turbine Temperature
LPT	: Low Pressure Turbine
MTOP	: Maximum Take-Off Power
NH	: High Pressure Compressor Speed
NL	: Low Pressure Compressor Speed
NTOP	: Normal Take-Off Power
OAT	: Outside Air Temperature
PAC	: Power Assurance Check
PF	: Pilot Flying
PM	: Pilot Monitoring
PRESS	: Pressure
PT	: Power Turbine
SED	: Small Exit Duct
TSB	: Transportation Safety Board of Canada
Wf	: Fuel Flow

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1. PROCESS AND PROGRESS OF AIRCRAFT SERIOUS INCIDENT INVESTIGATION

1.1 Summary of the Serious Incident

The occurrence covered by this report falls under the category of “Failure of engine (limited to extensive damage to the interior of the engine)” as stipulated in Clause 6, Article 166-4 of the Civil Aeronautics Regulations of Japan, and, as such, is classified as an aircraft serious incident.

On August 12 (Tuesday), 2008, a Bombardier DHC-8-402, registered JA848C, operated by Japan Air Commuter Co., Ltd. as scheduled Flight 2409, bound for Kagoshima Airport from Osaka International Airport, aborted the takeoff at 16:27 Japan Standard Time (JST: unless otherwise stated all times are indicated in JST, UTC+9h), because the No. 1 engine generated abnormal noise and lost power during the takeoff roll.

There were 68 persons on board, including the Pilot in Command, four other crewmembers and 63 passengers; no one was injured associated with this serious incident.

1.2 Outline of the Serious Incident Investigation

1.2.1 Investigation Organization

On August 13, 2008, the Aircraft and Railway Accidents Investigation Commission (ARAIC) designated an investigator-in-charge and two other investigators for investigation of this serious incident.

1.2.2 Representative and Adviser from Foreign State

An accredited representative and advisers from Canada, as the State of Design and Manufacture of the aircraft involved in this serious incident, participated in the investigation.

1.2.3 Implementation of the Investigation

August 13 and 14, 2008	Examination of the aircraft and the engine; interviews
August 20, 2008	Examination of the engine
September 2 and 3, 2008	Engine disassembly investigation at the engine manufacturer’s plant in Canada in the presence of the representatives from the Transportation Safety Board of Canada (TSB)

1.2.4 Provision of Factual Information to the Civil Aviation Bureau

On August 21, 2008, the ARAIC provided the Civil Aviation Bureau with the information obtained through the fact-finding investigation regarding the engine interior damage (detachment and falling off of part of the low pressure turbine vane segments, fractured material in part of the high pressure turbine shroud, etc.).

1.2.5 Comments from Parties Relevant to the Cause of the Serious Incident

Comments were invited from parties relevant to the cause of the serious incident.

1.2.6 Comments from the Participating State

Comments were invited from the participating state.

2. FACTUAL INFORMATION

2.1 History of the Flight

On August 12, 2008, the Bombardier DHC-8-402, registered JA848C (hereinafter referred to as “the Aircraft”), operated by Japan Air Commuter Co., Ltd. (hereinafter referred to as “the Company”) as Flight 2409 on a scheduled service, was to fly from Osaka International Airport (hereinafter referred to as “the Airport”) bound for Kagoshima Airport.

The Pilot in Command (hereinafter referred to as “the PIC”) took the left seat as the PF (pilot flying: pilot primarily responsible for aircraft control) while a trainee pilot took the right seat as the PM (pilot monitoring: pilot primarily responsible for duties other than aircraft control) and the first officer was seated in a jump seat at the rear of the cockpit.

The history of the flight up to the time of the serious incident is summarized below, based on the statements of the flight crewmembers and a member of the maintenance staff, the data from the digital flight data recorder (hereinafter referred to as “the DFDR”) and the cockpit voice recorder (hereinafter referred to as “the CVR”), and the records of ATC communications.

2.1.1 Statements of the Flight Crewmembers and Maintenance Staff

(1) PIC

On the day of the serious incident, the departure of our flight was behind schedule as a result of an incident in which the No. 1 engine turbine temperature [*1] (hereinafter referred to as “the ITT”) display had turned red (the engine instrument needle had climbed past the red line and the digital indication numerals had turned red; see Figure 3) during takeoff when the Aircraft had been operated for the last flight but one (JAC3647 from Fukuoka to Kagoshima) to ours. Another flight crew was on duty for the last flight (JAC2406) that had arrived at Osaka from Kagoshima, and I was informed that the ITT remaining within the limit and no problem had arisen.

The Airplane Operating Manual (hereinafter referred to as “the AOM”) states that the display turns red when the ITT exceeds 845°C, but I had heard that no specific maintenance actions had been taken for the occurrences of this condition since the limit value of 880°C specified in the Aircraft Maintenance Manual (hereinafter referred to as “the AMM”) had not been exceeded. The logbook included an entry indicating that the display had turned red, and I heard that the engine was going to be replaced shortly.

During the takeoff briefing, I told the other crewmembers that I would call out “Reject” (rejected takeoff) if the ITT exceeded the red display threshold during the takeoff roll. With the engines started and stabilized, the ITT for the No. 1 engine was 470–480°C, about 50°C higher than that for the No. 2 engine.

I initiated a rolling takeoff on Runway 32R, while advancing the power levers at a slower rate than usual. At a speed of about 60 kt, I heard abnormal noise twice on the left-hand side that was not so loud. Immediately after that, the Aircraft’s nose seemed to pull slightly to the left and the ITT reading was close to the red line, so I immediately called out “Reject” to abort the takeoff and then I

[*1] Turbine temperature refers to the combustion gas temperature near the inter-turbine and is calculated based on the temperatures sensed by the multiple sensors installed on the exhaust duct.

temporarily stopped the Aircraft on the runway short of Taxiway C5. I did not observe any smoke or fire and the instruments did not indicate any sign of fire. The FADEC *2 and OIL PRESS warning lights were illuminated.

I taxied the Aircraft back to Spot 20 using the No. 2 engine alone.

(2) First officer

The trainee pilot took the right seat and I was seated in a jump seat (rear seat). I did not notice anything abnormal during the engine start and taxiing.

Takeoff was initiated on Runway 32R with the normal takeoff power (hereinafter referred to as "NTOP") setting. The ITT for both engines rose at the same time, then the left engine ITT continued to rise. The ITT display turned red and, at the same time, I heard a short ripping sound coming from the left-hand side and the Aircraft veered slightly to the left, following which the PIC called out "Reject".

I took it upon myself to inform the Tower of the Aircraft's stop on the runway. There was wind of 11–13 kt from the left.

(3) Trainee pilot

We entered Runway 32R after waiting just short of it and set the takeoff power. I heard tearing noises twice from the left-hand side during the takeoff roll and the PIC then called out "Reject". During deceleration, the "#1 ENG FADEC FAIL" warning light came on together with the master warning.

(4) Maintenance staff of the Company

Upon being informed of the ITT display having turned red on the flight from Fukuoka to Kagoshima on the day of the serious incident, I checked the AMM and found that it specified "NO ACTION" until the ITT exceeds 880°C. As the reported temperature was below that threshold, I took no action at that time.

Since the Aircraft's No. 1 engine tended to have a smaller ITT margin (the amount of temperature difference from the upper ITT limit *3), we discussed the time for replacement of the engine within the Company on August 12, 2008 (the day the serious incident occurred) and reached an agreement to replace the engine after the following day's operation, i.e., on August 13.

The engine underwent a borescope inspection (hereinafter referred to as "BSI" *4) on February 21, 2008, which revealed minor damage on the SED *5, so the area was subjected to follow-up monitoring since then. Inspections detected no deterioration exceeding the limits in other areas of the engine, including in the shrouds of the high-pressure turbine (hereinafter referred to as "the HPT"). Records, including photos, are not kept for those areas in which inspections did not reveal any damage.

2.1.2 History of the Flight based on the Records of DFDR, CVR and ATC Communications

The ITT during the takeoff ground roll was about 535°C for the No. 1 engine and about 485°C for the No. 2 engine.

16:26:51 The Tower cleared the Aircraft for takeoff.

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*2 FADEC means computerized engine control or a system for such control.

*3 The upper ITT limit varies at the NTOP setting depending on the OAT.

*4 BSI is an inspection whereby an endoscope is used to observe the inside of the part being inspected.

*5 The SED refers to the outlet area of the engine's combustion chamber.

16:26:57	The trainee pilot called back the clearance to the Tower. The trainee pilot responded to the PIC's "takeoff" callout by saying, "Roger." The sound of the engines grew louder. The ITT for both engines gradually increased.
16:27:23	The trainee pilot called out "Eighty" and the PIC responded by saying, "Check."
16:27:24	The torque for the No. 1 engine momentarily dropped to zero (%) and, at the same time, the longitudinal acceleration of the Aircraft began to decrease. The ITT for the No. 1 engine exceeded 845°C and the engine generated abnormal noise.
16:27:26	The PIC called out "Reject" and the power lever angles for both engines were decreased.
16:27:27	The Aircraft reached a speed of about 90 kt and then slowed down.
16:27:34	The master caution light came on. (A chime sounded once.)
16:27:36	The "#1 ENG FADEC FAIL" light came on and, at the same time, the master warning light came on. (A chime sounded repeatedly.)
16:27:42	The first officer reported to the Tower that the takeoff had been aborted and that the Aircraft would stop on the runway.

The serious incident occurred at 16:27 on Runway A of the Airport (latitude 34°47'18"N, longitude 135°26'14"E).

(See Figures 1, 9 and Photo 1.)

2.2 Injuries to Persons

There were no deaths or injuries.

2.3 Damage to the Aircraft

2.3.1 Extent of Damage

The inside of the No. 1 engine was extensively broken. The Aircraft suffered no other damage.

2.3.2 Damage to the Aircraft Components

The engine's combustion gas from the combustion chamber flows through the SED, the HPT vane, the HPT, the low-pressure turbine (hereinafter referred to as "the LPT") vane, the LPT, the inter-turbine vane, the 1st stage power turbine (hereinafter referred to as "the PT"), the PT vane and the 2nd stage PT, in that order, and finally goes out through the exhaust duct. The HPT shroud, made up of 20 segments, forms a cover around the periphery of the HPT. The LPT vane consists of 7 segments, each having four vane airfoils (stator vane), so the LPT vane has a total of 28 vane airfoils. These vane airfoils are connected to the inner and outer drums. (See Figures 4, 5, 6, 7 and Photo 20.)

The cooling air for the HPT shroud flows from the turbine support case side and is led into the cooling air cavity due to the difference in pressure between these locations; it then passes through the cooling holes provided in the leading edge of the HPT shroud and flows into the gas path. (See Figure 5 and Photo 26.)

The visual inspection and BSI conducted on the No. 1 engine revealed the following:

(1) The external appearance of the engine case did not show anything abnormal.

(2) The compressor section had no special conditions suggesting any abnormalities. (See Figure 4.)

(3) The inside surface of the SED at the outlet of the combustion chambers were damaged in multiple locations. (See Figure 4 and Photo 2.)

(4) The HPT vane showed no major damage but had black soot deposits on its surface. (See Figure 4 and Photo 2.)

(5) The blades on the entire circumference of the HPT showed no significantly fractured material even though there was apparent deterioration on their leading edge and tip. There were soot deposits on the downstream end surfaces of the HPT blades. (See Photos 3, 4, 5.)

(6) Of a total of 20 HPT shroud segments, those located approximately between the 11 o'clock *[6] and 4 o'clock positions were successively fractured. (See Figure 6 and Photo 4.)

(7) Of a total of seven LPT vane segments, one segment's inner drum had detached and fallen off. This inner drum was rhomboidal in shape and found near the 2 o'clock position with one sharp-angled edge against the LPT vane and the opposite edge against the inter-turbine vane. (See Figure 7 and Photos 5, 6, 9, 10, 20.)

All four vane airfoils of the LPT vane segment with the detached and fallen inner drum were fractured and multiple vane airfoils in the vicinity of the segment were significantly deteriorated. (See Photos 6, 7, 19, 20.)

(8) The outer halves of all the LPT blades had broken off to almost the same length on the entire circumference of the LPT, each at about the midpoint along the length. When rotated by hand, the LPT dragged against the detached and fallen inner drum of the LPT vane segment from time to time. (See Photo 8.)

(9) The blades on the entire circumference of the 1st and 2nd stage PTs had broken off at various heights. The PT vane airfoils also showed edge damages on the entire circumference. (See Photos 11, 12.)

(10) Multiple dents were found on the inner dome of the exhaust duct, some of which were punctured. (See Photo 12.)

2.4 Personnel Information

(1) PIC Male, aged 51	
Airline Transport Pilot Certificate (Airplane)	August 3, 1993
Type rating for DHC8	March 15, 2007
Class 1 Aviation Medical Certificate	
Term of validity	Until November 29, 2008
Total flight time	13,018 h 15 min
Flight time in the last 30 days	58 h 50 min
Flight time on the type of aircraft	939 h 10 min
Flight time in the last 30 days	58 h 50 min
(2) First officer Male, aged 30	
Commercial Pilot Certificate (Airplane)	March 18, 2004
Type rating for DHC8	April 17, 2008
Instrument rating	May 10, 2007
Class 1 Aviation Medical Certificate	

*[6] Circumferential positions of the engine centering on its rotational axis are expressed by analogy to positions of the hour hand of a clock as viewed forward from the rear of the engine.

Term of validity	Until November 19, 2008
Total flight time	469 h 51 min
Flight time in the last 30 days	65 h 37 min
Flight time on the type of aircraft	166 h 10 min
Flight time in the last 30 days	65 h 37 min

(3) Trainee pilot Male, aged 34

Commercial Pilot Certificate (Airplane)	July 3, 2000
Type rating for DHC8	May 28, 2008
Instrument rating	June 4, 2001
Class 1 Aviation Medical Certificate	
Term of validity	Until July 23, 2009
Total flight time	511 h 24 min
Flight time in the last 30 days	39 h 59 min
Flight time on the type of aircraft	70 h 40 min
Flight time in the last 30 days	39 h 59 min

2.5 Aircraft Information

2.5.1 Aircraft

Type	Bombardier DHC-8-402
Serial number	4121
Date of manufacture	April 8, 2006
Certificate of airworthiness	DAI 20-040
Term of validity	Until April 27, 2009
Category of airworthiness	Airplane, Transport category (T)
Total flight time	4,758 h 10 min
Flight Time in service since last periodical check (1C check on March 4, 2008)	952 h 01 min

(See Figure 2.)

2.5.2 Engine

Type	Pratt & Whitney Canada PW150A	
	No. 1 engine	No. 2 engine
Serial number	PCE-FA0281	PCE-FA0167
Date of manufacture	December 22, 2005	February 25, 2003
Total time in service	4,758 h 10 min	6,702 h 10 min
Total cycles in service	6,207	10,418

(See Figure 4.)

2.5.3 Maintenance History and Other Relevant Information on the No. 1 Engine

Specific timing for a regular overhaul has not been specified for this type of engine but, as described in

2.12.1 (6), it is required that the turbine section in conjunction with the combustion section undergo special detailed inspection using the BSI method before the first 4,000 hours and thereafter every 1,500 hours.

The No. 1 engine had been installed during the manufacture of the Aircraft and was never removed since then. The Company has a comprehensive maintenance contract with the engine manufacturer, which includes engine condition trend monitoring (hereinafter referred to as "the ECTM" [*7]). The Company regularly downloads ECTM data and sends it to the ECTM data analysis company appointed by the engine manufacturer (hereinafter referred to as "the ECTM analysis company").

Major maintenance history and other relevant events are summarized below.

(1) February 21, 2008; total time in service 3,806 h 09 min
The Company conducted BSI to be described in 2.12.1 (6) in accordance with the AMM instructions to be described in 2.12.1 (2). The inspection revealed minor damage in multiple locations on the SED, but since the damage in all these locations was within the limits, the SED was placed under follow-up monitoring at 500 flight-hour intervals.

(2) April 26, 2008; total time in service 4,128 h 31 min
The Company conducted BSI as part of the SED follow-up monitoring and determined that the damage had not progressed.

(3) May 23, 2008; total time in service 4,280 h 24 min
The ECTM analysis company notified the Company that the engine status had changed to "Yellow" to be described in 2.12.1 (8) and that the engine might have reduced ITT margin due to hot section deterioration. The Company became aware of the notification on May 24, 2008.

(4) July 13, 2008; total time in service 4,578 h 17 min
The Company conducted BSI as part of the SED follow-up monitoring, determining from the results that the damage had progressed but its extent was within the limits. The inspection also revealed erosion on the HPT vane and the Company placed the HPT vane under follow-up monitoring at 250 flight-hour intervals. Water rinsing of the engine was also carried out. The power assurance check (hereinafter referred to as "PAC") conducted at the time revealed that the ITT margin was 7°C.

(5) August 8 and 9, 2008; total time in service 4,741 h 48 min
The Company conducted BSI as part of the HPT vane follow-up monitoring, finding that the damage had progressed but determining it to be within the limits.

(6) August 11, 2008; total time in service 4,754 h 45 min
During the takeoff on Flight JAC2419 (from Osaka to Kagoshima), the ITT display turned red, with the temperature climbing to about 861°C. In accordance with the AMM instructions to be described in 2.12.1 (1), no special actions were taken.

(7) August 12, 2008; total time in service 4,758 h 10 min
During the takeoff on Flight JAC3647 (from Fukuoka to Kagoshima), the ITT display turned red, with the temperature climbing to about 856°C. In accordance with the AMM instructions to be described in 2.12.1 (1), no special actions were taken.

(8) Following the last event described above, the serious incident covered by this report took place on Flight JAC2409 (from Osaka to Kagoshima), at which point the total time in service of the Aircraft

[*7] The ECTM program is a process in which engine condition data from every flight is automatically recorded and changes in the data are used to estimate the trend of deterioration, which is then referred to in establishing the maintenance plan or for other purposes.

was less than about 1,000 hours as counted from the first BSI conducted on February 21, 2008, meaning that the time for conducting the first of the repeated inspections at 1,500-hour intervals to be described in 2.12.1 (6) had not yet been reached.

2.6 Meteorological Information

Aeronautical weather observations for the Airport around the time of the serious incident were as follows:

16:00 Wind direction 230° (variable 190–270°); Wind velocity 11 kt; Visibility 50 km
Cloud: Amount FEW, Type Cumulonimbus, Cloud base 2,500 ft
Amount SCT, Type Unknown, Cloud base Unknown
Temperature 34°C; Dew point 21°C
Altimeter setting (QNH) 29.78 inHg

17:00 Wind direction 240° (variable 200–300°); Wind velocity 11 kt; Visibility 50 km
Cloud: Amount FEW, Type Cumulonimbus, Cloud base 2,500 ft
Temperature 33°C; Dew point 22°C
Altimeter setting (QNH) 29.78 inHg

2.7 Information on the DFDR and the CVR

The Aircraft was equipped with a DFDR (P/N 980-4700-027) manufactured by Honeywell Aerospace, U.S.A. and a CVR (P/N 980-6022-011) also manufactured by Honeywell Aerospace, U.S.A. The records retained by the DFDR and CVR covered the events that had taken place during the time of the serious incident. The DFDR time was determined by correlating the DFDR-recorded VHF transmission keying signals with the NTT (Nippon Telegraph and Telephone Corporation) speaking clock recorded on the ATC communication records.

2.8 Information on the Serious Incident Site

The Airport has two runways: Runway 14L/32R (Runway A), located on the east side of the airport, is 1,828 m long and 45 m wide, and Runway 14R/32L (Runway B), located on the west, is 3,000 m long and 60 m wide.

About 200 metal fragments (the largest of which measured about 35 mm by 20 mm) were found scattered over an area about 20 m wide and 50 m long on the west side of Runway A near Taxiway C3.

Since no debris was found during the runway inspection conducted immediately after the serious incident, five aircraft took off from Runway A and five aircraft landed on Runway A thereafter. Upon receiving a report about metal pieces found in the exhaust duct of the Aircraft's engine, another inspection of Runway A was conducted and metal pieces were found scattered on the runway, so Runway A was closed from 18:00 to 21:30 on that day for debris collection and cleaning.

It was confirmed that none of the aircraft that had made takeoffs and landings on Runway A before the debris collection experienced any abnormalities.

(See Figure 1.)

2.9 ITT Values Recorded on the DFDR

The Aircraft's DFDR records for the period of August 7 to 12, 2008 showed that the No. 1 engine had experienced ITT values exceeding 845°C, beyond which the ITT display turns red (marked with * below), six times in flights prior to the occurrence of the serious incident during NTOP setting. The maximum ITT values on August

11 and 12 and the relevant flights are shown below.

August 11	07:44	JAC2300	During takeoff from Matsuyama Airport	818°C
August 11	09:06	JAC2303	During takeoff from Osaka International Airport	825°C
August 11	10:24	JAC2304	During takeoff from Matsuyama Airport	828°C
August 11	11:59	JAC2435	During takeoff from Osaka International Airport	*861°C
August 11	13:44	JAC2436	During takeoff from Miyazaki Airport	811°C
August 11	15:27	JAC2439	During takeoff from Osaka International Airport	*869°C
August 11	17:05	JAC2440	During takeoff from Miyazaki Airport	819°C
August 11	19:06	JAC2419	During takeoff from Osaka International Airport	*860°C
August 12	08:05	JAC3640	During takeoff from Kagoshima Airport	*854°C
August 12	09:46	JAC3643	During takeoff from Fukuoka Airport	843°C
August 12	11:37	JAC3644	During takeoff from Kagoshima Airport	*853°C
August 12	12:55	JAC3647	During takeoff from Fukuoka Airport	*856°C
August 12	14:34	JAC2406	During takeoff from Kagoshima Airport	833°C

2.10 ECTM Data

The changes in parameters as read from the ECTM graph for the No. 1 engine showed the dITT (amount of difference from the reference ITT value [*8]) becoming positive and then continuing to rise in the few months prior to the serious incident, whereas the dNH (amount of difference from the reference high-pressure compressor speed value) showed a downward tendency. The dNL (amount of difference from the reference low-pressure compressor speed value) showed no significant changes, but the dWf (amount of difference from the reference fuel flow value) showed an upward tendency.
(See Figure 8.)

2.11 Tests and Research for Fact Finding

2.11.1 Engine Disassembly Investigation

As part of the investigation of the serious incident, disassembly investigation on the Aircraft’s No. 1 engine was conducted at the engine manufacturer’s plant (in Canada) in the presence of TSB representatives. The results of the examination are described below in the order of the teardown process, starting with the rear end of the engine.

(1) There was no external damage on the engine. While the high- and low-pressure rotors turned freely when rotated by hand, there was a grinding noise when the PT was rotated. (See Figure 4.)

(2) When visually examined from the engine exhaust end, all of the 2nd stage PT blades were found to be fractured at various heights. The exhaust duct inner dome was dented and punctured by broken pieces, and removal of the exhaust duct revealed deformation of the outer drum. (See Photo 12.)
The 2nd stage PT blades had many impact dimples and re-solidified molten material deposits. The fractured surfaces of these blades showed features of tensile overload fracture. (See Photo 12.)

(3) The PT vane airfoils showed impact tears, and the 2nd stage PT blade shroud was partially damaged.

(4) All of the 1st stage PT blades were found to be fractured at various heights and many impact dimples

*8 The reference value varies depending on altitude, speed, OAT, etc. This also applies to the reference values for dNH, dNL and dWf.

were found along with re-solidified molten material deposits. The fractured surfaces of these blades showed features of tensile overload fracture.

(5) The trailing edge of the inter-turbine vane's outer drum had impact marks located approximately at the 6 o'clock to 9 o'clock positions. The inner drum from one of the LPT vane segments was found lodged in the inter-turbine vane. (See Photo 13.)
Removal of the inter-turbine vane revealed its two vane airfoils at the 1 o'clock to 2 o'clock positions with severe heat erosion on their leading edge. These two vane airfoils were perforated, exposing the inner core to the gas path. The outer drum area located approximately between the 3 o'clock and 9 o'clock positions was covered with re-solidified molten material deposits. It made possible to take out the inner drum that had detached from the #2 LPT vane segment. (See Photos 14, 15, 18.)

(6) All of the LPT blades on the LPT disc assembly were found to be fractured at approximately midway along their length. The LPT blades had many impact dimples together with re-solidified molten material deposits. (See Photos 15, 16.)

(7) The LPT shroud segments were covered with re-solidified molten material deposits and the #1 segment was punctured by impact. (See Photos 16, 17.)

(8) The LPT vane assembly showed severe heat distress in the area approximately between the 10 o'clock and 4 o'clock positions, while the vanes located between the 12 o'clock and 2 o'clock positions were completely burnt away. All four vane airfoils on the #2 LPT vane segment were missing and the inner drum had detached and fallen off. Three vane airfoils on the #1 LPT vane segment were missing but one vane airfoil remained on the segment with half of it lost due to heat erosion. The missing vane airfoil side of the #1 segment's inner drum was lifted towards the gas path. Two vane airfoils on the #3 LPT vane segment were missing due to heat erosion. (See Figure 7 and Photos 18, 19, 20.)

(9) The HPT disc assembly had no visible damage on the blades when viewed from the trailing edge side. Due to damage to the HPT shroud segments, the HPT blade tip clearance was found to be excessive in the section located approximately between the 11 o'clock and 4 o'clock positions. (See Photo 21.)
Removal of the HPT disc assembly revealed heat erosion on the leading edge of the blades, and the cooling cores at the tips of six of the blades were exposed. All of the HPT blades tips were heat eroded, oxidized and rubbed resulting in the exposure of their internal core passages to combustion gas at several locations. (See Photos 22, 23.)

(10) The HPT shroud had four consecutive segments (#20, #1, #2 and #3) completely burnt away. Two segments (#4 and #5) next to one end of these consecutive segments had their surfaces completely burnt away and the surfaces of two other segments (#19 and #6) were partially lost. (See Figure 6 and Photos 24, 25, 26.)
The surface of the #18 HPT shroud segment showed a perforation, thus exposing the cooling cavity to the gas path, and the leading edge of the shroud was heat eroded. Some of the other HPT shroud segments showed axial cracking in the central section of the shroud surface. The turbine support case showed heat distress and cracks resulting from exposure to combustion gas. (See Figures 5, 6 and Photos 24, 25, 26.)

(11) The HPT vane assembly was covered with soot, but the vane airfoils were free of major damage. The HPT vane support was burned on the outer side and covered with re-solidified molten material deposits at the location corresponding to the damaged section of the HPT shroud.

(12) The SED had missing heat shields at 11 locations due to heat distress, but it had no damage in the area at approximately the 1 o'clock position. (See Photo 27.)

(13) The outer liner of the combustion chamber showed axial cracking in the dome. The inner liner of the combustion chamber had no obviously visible damage.

(14) The fuel nozzles were the ones originally installed on the engine, and their orifices were found to be clean. The air blast area of the fuel nozzles was covered with a light deposit of black soot.

(15) Fuel nozzle test revealed that the primary and secondary fuel flow rates were lower than normal for some nozzles, and the primary and secondary spray cone angles were slightly larger or smaller than normal for some nozzles. However, all nozzles showed no deviations from the standard as a result of the spray pattern testing conducted. Retesting of the fuel nozzles conducted after removing the soot deposits by ultrasonic cleaning revealed that all of the nozzles were normal both in primary and secondary fuel flow rates and in the quality of primary and secondary sprays.

(16) The HP shaft showed signs of rubbing against the LP shaft, but the inspection conducted after removal of the cold section showed no major rubbing damage. Light rubbing marks were found in the HP impeller vane exducer area and on the 3rd stage LP compressor blade tips. (See Figure 4.)

2.11.2 Comments from the Engine Manufacturer

The engine manufacturer has expressed the following views.

(1) It was in a normal deterioration mode having progressed gradually over time that the HPT shroud segments underwent thermal cracking and heat erosion/oxidation. This type of deterioration can be found by means of BSI and ECTM.

The damage to the SED is not a rare case, as the distribution of temperature in the gas path is not uniform, and it is known from experience that this does not have a direct influence on the progress of deterioration of the HPT shroud.

(2) It is shown by the ECTM trend graph that the NH (high-pressure compressor speed) was declining and the ITT and fuel flow were rising; this is the normal sign indicating a deteriorated hot section.

The engine manufacturer believes that the tasks specified in the Fault Isolation Manual (hereinafter referred to as "the FIM") to be described in 2.12.1 (4) had been carried out within two to three weeks of the ECTM engine state changed to "Yellow," BSI would have been conducted and consequently the engine would have been removed at an earlier timing.

(3) The ITT display had turned red multiple times prior to the occurrence of this serious incident. Abnormal conditions should be considered whenever the ITT indication is in the red zone, so the qualified maintenance personnel should have carried out troubleshooting by performing the FIM tasks to be described in 2.12.1 (5) before considering returning the Aircraft to service

(4) The engine manufacturer believes that the intervals for hot-section BSI, i.e., 4,000 flight hours for the first inspection and thereafter every 1,500 flight hours, should not be changed.

It is normally possible to detect hot-section deterioration by means of ECTM. As shroud deterioration should become evident earlier than 4,000 flight hours, they would have enough time before the first warnings are issued.

The engine manufacturer has the view that, judging from the conditions in which the HPT blades and shroud were found at the time of this serious incident, the related areas of the engine had already become severely deteriorated at the point of about 3,800 flight hours, the time when BSI was conducted.

(5) The current HPT shroud design and material are adequate. The Aircraft's HPT shroud deteriorated gradually through normal operation over time but the engine was used beyond the acceptable limits because the condition of the shroud was not assessed per recommendations provided prior to the serious incident. Therefore, this event is non-basic to the engine as it results from factors beyond the engine manufacturer's reasonable control.

2.12 Additional Information

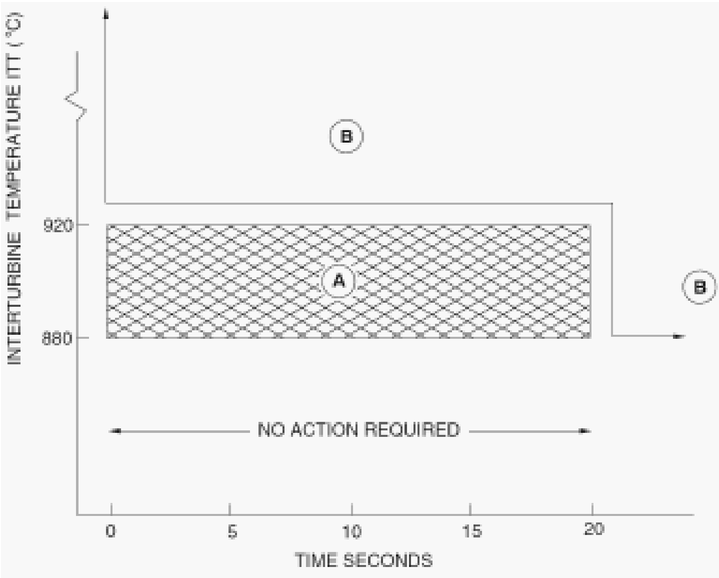
2.12.1 The AMM and Other Relevant Publications

(1) The AMM for the Aircraft describes the following regarding the engine operating limits. (Excerpts from the AMM)

TASK 05-11-00-992-802
Engine Time Limits, Operating Limits and Leading Particulars
３. *Engine Operating Limits and Leading Particulars*
Ｃ. *Overtemperature Limits*
(1) Overtemperature limits for the PW150A (BS885) engine are shown in Figure 602.
Ｆ. *The Tables that follow give the engine operating limits and leading particulars.*

Engine Operating Limits

	STEADY STATE	*TRANSIENT*
Inter Turbine Temperature (ITT)	*880°C (1616°F) max.*	*920°C (1688°F) for 20 seconds max.* *920°C (1688°F) 20 seconds max. during start.* *Refer to Figure 602.*



Engine – Overtemperature Limits (Starting and Transient)

Figure 602

AREA A

NO ACTION REQUIRED IF CONDITION OCCURS DURING START (SEE NOTE 1), OTHERWISE DETERMINE AND CORRECT CAUSE OF OVERTEMPERATURE. RECORD IN ENGINE LOG BOOK.

(1) NO ACTION REQUIRED IF CONDITION OCCURS DURING TRANSIENT (SEE NOTE 2).

(2) IF CONDITION OCCURS DURING STEADY STATE, DETERMINE AND CORRECT CAUSE OF OVERTEMPERATURE. RECORD IN ENGINE LOG BOOK.

AREA B

(1) INVESTIGATE AND CORRECT CAUSE OF OVERTEMPERATURE.

(2) REMOVE TURBOMACHINERY MODULE AND RETURN TO AN OVERHAUL FACILITY FOR AN INSPECTION AS IT IS WRITTEN IN THE PRATT & WHITNEY CANADA PW150A ENGINE MANUAL.

NOTE 1: TROUBLE SHOOTING IS RECOMMENDED (REF. ENGINE FAULT ISOLATION) WHEN TEMPERATURE IS CONSISTENTLY IN AREA “A”.

NOTE 2: TRANSIENT IS DEFINED AS CHANGE IN TEMPERATURE CAUSED BY MOVEMENT OF THE POWER OR CONDITION LEVER OR AN ALTITUDE CHANGE.

(2) The Aircraft’s AMM describes the following regarding BSI. (Excerpts from the AMM)

TASK 72-00-00-290-805

Borescope Inspection of the Combustion Chamber Liner Assembly, Small Exit Duct, HP Turbine Vane Segments, HP Shroud Segments, and HP Turbine Blades

４. Procedure

G. Do the steps that follow to inspect the HP stator, shroud segments, and blades:

(3) Use different ports to examine fully the HP stator and shroud segments for damage

M. Serviceable limits for the HP turbine shroud segments are shown in Table 609.

Table 609 – HP Shroud Segment Inspection

Inspection Location (Refer to Figure 618)	*Serviceable Limits (Refer to Notes 1 and 2)*			*Repair damage in 50 flight hours or less.*
	If damage is in these limits, it is not necessary to do more borescope inspection.	*If damage is in these limits, continue to do borescope inspections at intervals of 500 flight hours.*	*If damage is in these limits, continue to do borescope inspections at intervals of 250 flight hours.*	
HP Shroud Segment	*Erosion of the coating down to the base materi-al (the condi-tion is seen as a colour change).*	*Erosion of the shroud lip but not through the back wall.*	*Erosion of the shroud up to penetration of the cooling cavity. Erosion of the adjoining segment surfaces up to 0.200 in. (5.0 mm).*	*If damage is more than the service-able limits. If there are signs of blade tip rub on a segment with a large amount of erosion or distortion.*
NOTE: 1. Shroud damage in the limits specified is acceptable if the engine Power Assurance is within limits. 2. If you operate the engine with erosion damage through the full thickness of the shroud segments, it can cause erosion damage to the Turbine Support Case.				

The following caption is indicated in the “ADJOINING SEGMENTS” figure in Figure 618.

EROSION OF THE UPSTREAM LIP IS ACCEPTABLE IF IT DOES NOT GO THROUGH TO THE COOLING CAVITY

(3) The Aircraft’s AMM describes the following regarding PAC. (Excerpts from the AMM)

TASK 71-00-00-868-806
Engine Power Assurance Check

3. Procedure

B. Do a power assurance check of the engine using an EMU as follows:

NOTE: All the power assurance charts include an allowance for a performance decrease when the engine is installed in the nacelle.

(3) Examine the engine parameters:

(a) For a normal power assurance check, do the items that follow:

1. Do the necessary troubleshooting if NH, NL, ITT or Wf are more than the maximum limits (Refer to FIM 71-00-00-810-808).

NOTE: The engine is serviceable if Wf is more than the limit but all other parameters are in the limits. You can use Wf as an indicator. Make sure that the other parameters (NH, NL, ITT) are accurate.

2. *If ITT is less than 5°C (9°F) below the maximum limit, do another power assurance check before one week.*
3. *If NH or NL is less than 0.25% below the maximum limit, do another power assurance check before one week.*

(b) *For a power assurance check after a hot section inspection (HSI), do the steps that follow.*

NOTE: If the engine was tested in a test cell after the HSI, you can use those test results to calculate the performance margins.

1. *The recommended minimum NH, NL and ITT margins are shown in Table 502.*

Relative Margins

NH	*NL*	*ITT*
1.6%	*1.0%*	*37 degC*
NOTE: Sufficient NH, NL, ITT margins let hot sections complete an average life for an operator's fleet. The life can be different for different operators because the operating conditions are not always the same.		
NOTE: When an engine is installed in an airframe after a shop visit it is usual that the NH, NL and ITT margins can be different from the margins calculated from the test cell performance test sheet. The differences that follow are usual; NH (±0.3%), NL (±0.3%), ITT (±5 degC).		

2. *If the engine does not have the recommended margins after an HSI, the life of the hot section can change. You can either:*
   - *Remove the engine and do the procedure for engine rotor speed matching as it is written in the Pratt and Whitney Canada PW150A Hot Section Inspection manual.*

     or
   - *Operate the engine and accept the reduced hot section life, if the engine is in the power assurance limits.*

(c) *If NH, NL, ITT and Wf recorded are more than the values recorded initially or if the margins are smaller than recommended, do a check of the instrumentation. If it is necessary, refer to Fault Isolation Manual (PSM 1-84-23).*

(4) The Aircraft's FIM describes the following regarding engine performance deterioration or trend shift. (Excerpts from the FIM)

TASK 71-00-00-810-808

Performance Deterioration or Trend Shift – Fault Isolation

4. Fault Confirmation

Figure 201

A. *If necessary, do a Power Assurance Check (Refer to AMM TASK 71-00-00-868-806) or plot more ECTM data (Refer to AMM TASK 72-00-00-890-804) to see if there is performance deterioration or trend shift.*

(1) If the test shows no fault, do the Close Out.

(2) If the test shows a fault, do the Fault Isolation.

5. Fault Isolation

B. Examine the (ECTM) data (Refer to AMM TASK 72-00-00-890-804) or the Power Assurance data (Refer to AMM TASK 71-00-00-868-869) to find the change in the engine data and to see the recommended limits for maintenance action.

C. Compare the change in engine's performance with the options shown in Engine Parameters column. From the options shown, select the one describes the actual engine parameter change the best. Do the referenced tasks to find the cause of the engine performance change.

D. If the engine was not removed, get the ECTM or Power Assurance data and see if the performance deterioration was corrected. If the performance has not been corrected, do the referenced tasks for the other possible causes for the engine performance change.

Figure 201 Performance Deterioration/Trend Shift – Fault Isolation

ENGINE PARAMETER SHIFT				*PROBABLE DEFECT*	*ACTION REQUIRED*	*REFERENCE TASK*	*REMARKS*
ITT/T6	*NH*	*NL*	*WF*				
↗	↘	↗ →	↗ →	*HP TURBINE AREA PROBLEM*	*BORESCOPE INSPECT.*	*72-00-00-290-805*	*A 0.75% DROP IN NH INDICATES SIGNIFICANT HOT END DISTRESS. Wf AND ITT MAY NOT SHOW SIGNIFICANT INCREASE. A STEP CHANGE COULD INDICATE HP VANE SEGMENT DISTRESS.*

LEGEND → : NO SHIFT
↗ : SHIFT OVER TIME

(5) The Aircraft's FIM describes the following regarding the actions to be taken in the event of a sudden increase in ITT or abnormal ITT. (Excerpts from the FIM)

TASK 71-00-00-810-814

Engine #1 (#2), Sudden Increase/abnormal ITT - Fault Isolation

4. Fault Confirmation

A. Do an engine operational test (Refer to AMM TASK 71-00-00-868-805) to verify the fault.

(1) If the engine operational test does not show the fault, no maintenance action is necessary.

(2) If the engine operational test shows the fault, then do the fault isolation procedure.

5. Fault Isolation

C. Is the indicated turbine temperature (ITT) system correct (Refer to AMM TASK 77-21-01-720-801)?

If not, correct the system and do an engine operational test. If the problem is resolved, go to the close-out procedures to return to service. If not resolved, continue with the Fault Isolation procedure. If correct, continue with the Fault Isolation procedure.

I. *Do an engine operational test (Refer to AMM TASK 71-00-00-868-805). Is there still a problem?*

(1) *No. Do the close-out procedure to return to service.*

(2) *Yes. Do a power assurance check (Refer to AMM TASK 71-00-00-868-806) and continue with the Fault Isolation procedure.*

K. *Are there any gas path leaks?*

If yes, correct the gas path leaks and do an engine operational test. If the problem is resolved, go to the close-out procedures to return to service. If not resolved, speak to a Pratt & Whitney Canada Technical Representative.

If no, speak to a Pratt & Whitney Canada Technical Representative.

(6) The Aircraft's Maintenance Requirements Manual describes the following regarding the intervals for BSI-dependent special detailed inspection. (Excerpts from the Maintenance Requirements Manual)

SYSTEM/POWERPLANT MAINTENANCE PROGRAM

Task Number: 724000-201

Task Title: COMBUSTION SECTION

Task Description: Special Detailed Inspection (Borescope) of the Combustion Chamber Liner Components (Do the task in conjunction with 725000-202)

Interval: Threshold; New/Refurbished 4,000 EH
Repeat; 1,500 EH

Task Number: 725000-202

Task Title: TURBINE SECTION

Task Description: Special Detailed Inspection (Borescope) of the Turbine Gas Path Components (Do the task in conjunction with 724000-201)

Interval: Threshold; New/Refurbished 4,000 EH
Repeat; 1,500 EH

(7) The Company's AOM describes the following regarding the engine operating limits. (Excerpts)

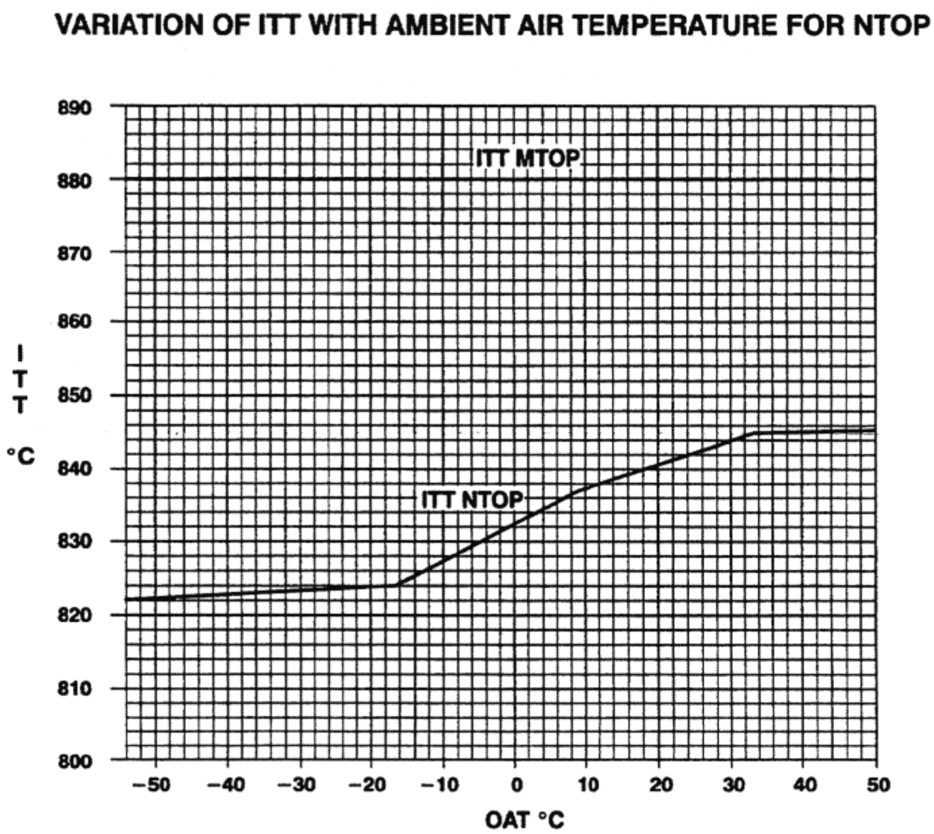
1 - 5 - 4 Power Plant

2. Operating Limits (Engine/Propellers)

ENGINE OPERATING LIMITS			
POWER SETTING	*MAX TORQUE %*	*MAX ITT °C*	(Omitted)
MAX TAKE-OFF (MTOP)	*106*	*880*	(Omitted)
NORMAL TAKE-OFF (NTOP)	*90.3*	*(7)*	(Omitted)

(7) Normal takeoff ITT limits relative to given ambient air temperatures are shown in Fig. 1-5-1.

Fig. 1-5-1 (Excerpts)



OAT (Outside Air Temperature)

With the engine power set to NTOP, the ITT display in the cockpit turns red when ITT exceeds the "ITT NTOP" values in Fig. 1-5-1.

(8) The engine manufacturer had provided operators with the following guidelines on ECTM alert criteria. The guidelines are intended as an aid for planning the troubleshooting schedule and is not included in the AMM or any other relevant documents.

ECTM Alert Criteria

Green • *Engines on green status do not show significant, unexplained ECTM shifts. Engines on this status continue to be reviewed regularly by the Altair* (contracted ECTM analysis company) *analyst; no action is required of the customer.*

Orange • *Gradual deterioration in engine performance.*
◦ *ITT between 15°C and 10°C margin (predicted or from PAC)*

Yellow • *Gradual deterioration in engine performance.*
◦ *ITT between 10°C and 5°C margin (predicted or from PAC)*
◦ *NH decrease greater than .25%*

• *Performance deterioration associated with external influences*
◦ *Bleed air leaks*
◦ *Malfunctioning instrumentation*

Red • *Rapid deterioration in engine performance.*
◦ *ITT increases at a rate in excess of 10°C per week.*
◦ *NH decreases at a rate in excess of .25% per week.*

• *Performance parameters approaching alert limits*
◦ *ITT within 5°C of zero margin (predicted or from PAC)*
◦ *NH decrease greater than 0.5%.*

Repeat PAC Criteria

Alert Level	*PAC Recommended Within (FH's)*
Orange	150
Yellow	100
Red	50

PAC Margin	*Recommended PAC Interval*
ITT margin < 15°C	*500 Flight Hours*
ITT margin < 10°C	*250 Flight Hours*
ITT margin < 5°C	*100 Flight Hours* *(Schedule removal)*

2.12.2 Actions taken by the Civil Aviation Bureau

Upon receipt of the factual information described in 1.2.4, the Civil Aviation Bureau issued

TCD-7354-2008 (Japanese Airworthiness Directive) on August 21, 2008 instructing the operators concerned in Japan to inspect the HPT shroud, the HPT blade and the LPT vane.

As a result of the inspections conducted, damage exceeding the tolerances was found on a total of five engines, including those on another of the Company's aircraft and on other operator's aircraft.

Necessary actions were subsequently taken on each of these engines.

3. ANALYSIS

3.1 Flight Crew Qualifications

The PIC, the first officer and the trainee pilot each possessed a valid airman competence certificate and a valid aviation medical certificate.

3.2 Airworthiness Certificate of the Aircraft

The Aircraft had a valid airworthiness certificate and had been maintained and inspected as prescribed.

3.3 Meteorological Conditions

It is considered highly unlikely that the prevailing weather at the time of this serious incident had any relevance to the occurrence of the incident.

3.4 Damage to the Engine

3.4.1 Process and Progress of the Damage

Based on the descriptions in 2.3.2 and 2.11.1, it is considered highly probable that the process and progress of the damage to the engine were as follows:

(1) Damage to the HPT shroud

As the condition observed on part of the remaining HPT shroud segments shows, thermal-stress cracking and heat erosion/oxidation occurred in the central section of one HPT shroud segment. The thermal cracking and heat erosion then progressed, allowing combustion gas to enter the cooling air cavity for the HPT shroud.

This caused localized disturbance in the differential-pressure-dependent flow of cooling air, which limited or interrupted the flow of air to the cooling holes provided on the leading edge of the HPT shroud. In addition, reversal in air flow occurred locally at the cooling holes on the HPT shroud leading edge, which let combustion gas into the air cooling cavity, resulting in oxidation of the inner wall of the HPT shroud segment.

The thermal cracking and heat erosion/oxidation spread to the adjoining HPT shroud segments, which caused growing deterioration of the shroud. As the deterioration advanced further, the HPT blade clearance increased, which in turn caused the combustion gas pressure to drop, leading to slower NH (high-pressure compressor speed) and increased ITT. To compensate for the eventual drop in output, the FADEC increased the Wf (fuel flow), and consequently, both the increased ITT and Wf accelerated the oxidation process, further advancing the deterioration of the HPT shroud. (See Figure 5 and Photos 24, 25, 26.)

(2) Damage to the LPT vane, LPT blades and inter-turbine vane

Material that had resulted from the deterioration of the HPT shroud melted, adhered to the downstream LPT vane and then re-solidified, forming deposits. This impaired the cooling effect of the vane and caused heat distress. The material was also deposited on the inter-turbine vane located downstream, impairing the cooling effect for the inter-turbine vane and opening a hole through the two vane airfoils located at approximately the 1 o'clock and 2 o'clock positions as a result of progressing heat erosion. As the deterioration of the LPT vane thus advanced, all four vane airfoils in the #2 LPT vane segment were lost; since the supports had been lost, the segment's inner drum then fell off. (See Figures 4, 5, 7 and Photos 5, 6, 7, 14, 19, 20.)

Being rhomboidal in shape, the LPT vane segment's inner drum that had fallen off became lodged between the LPT vane and the inter-turbine vane with one sharp-angled edge trapped in the former and the opposing edge in the latter. Against this fallen and trapped inner drum, the LPT blades that were rotating between the LPT vane and the inter-turbine vane struck and the blades on its entire circumference broke off to almost the same length. (See Figure 4 and Photos 8, 9, 10, 13, 15, 16, 18, 20.)

(3) Damage to the PT blades, PT vane and exhaust duct

The broken pieces of the LPT blade were carried downstream by combustion gas and hit against the 1st stage PT while breaking all blades on its entire circumference. Then, the resulting broken pieces together with those from the LPT blades damaged the PT vane airfoils and broke the 2nd stage PT blades before being carried outside the engine while causing damage to the exhaust duct. (See Photos 11, 12.)

3.4.2 Relationship to the SED Conditions

The locations of major damage were between the 11 o'clock and 4 o'clock positions (especially between the 12 o'clock and 2 o'clock positions) for the HPT shroud, between the 10 o'clock and 4 o'clock positions (especially between the 12 o'clock and 3 o'clock positions) for the LPT vane, and between the 1 o'clock and 2 o'clock positions for the inter-turbine vane. As these locations almost agree with each other, it is considered highly probable that the material produced in the deterioration process in the upstream section was carried along the gas path and affected the downstream stage elements. (See Figures 6, 7 and Photos 14, 19, 21, 24, 25.)

As described in 2.11.1 (11) and (12), the HPT vane located upstream of the HPT shroud had no major damage, and the SED located further upstream from the HPT vane had, despite the damage in 11 locations on it, smaller damage than with the other elements in the location between the 12 o'clock and 4 o'clock positions, the location that roughly corresponds to the locations of damage in the HPT shroud and the elements that follow it. It is therefore considered unlikely that the damage on the SED contributed to the deterioration of the HPT shroud that is located downstream from it. (See Figure 5 and Photo 27.)

To sum up, it is considered highly probable that the progress of deterioration in the HPT shroud gave rise to the detachment and falling off of the LPT vane segment's inner drum and, secondarily to this, caused damage to the LPT blades and the further downstream stage elements such as the PT blades. It is also considered highly probable that a sudden power drop resulting from the damaged LPT blade and PT blades directly led to the rejected takeoff. (See Figures 4, 9.)

3.5 Implementation of BSI

As described in 2.5.3 (1), the Company carried out BSI on the No. 1 engine on February 21, 2008, at about 3,800 hours in total service time in accordance with AMM procedures described in 2.12.1 (2). As this BSI includes inspection of the HPT shroud segments, it is considered highly probable that the segments were inspected during the BSI. Although the BSI found damage on the SED and the damage was then placed under follow-up monitoring, no record was made regarding the HPT shroud segments. It is therefore considered highly probable that no major damage was then found on the HPT shroud segments. While the serious incident took place about 950 hours (five and a half months) after the BSI, the engine manufacturer stated that, as described in 2.11.2, part of the HPT shroud had already reached a deteriorated condition when the BSI was conducted.

As described in 2.5.3 (2) and (4), BSI was conducted on April 26 and July 13, 2008, as part of the SED follow-up monitoring. Since the follow-up monitoring is conducted only on a specific area, it is considered highly probable that the HPT shroud segments were not checked during the inspection at that time.

3.6 Change in Engine Status Based on ECTM Data

As described in 2.5.3 (3), on May 24, 2008 the Company was notified by the ECTM analysis company that the engine status had changed to "Yellow."

According to the engine manufacturer's guidelines described in 2.12.1 (8), it was recommended that PAC be conducted within 100 flight hours for the "Yellow" status. It was on July 13, 2008, or about 300 flight hours (about seven weeks) after the notification, that the Company conducted PAC as described in 2.5.3, and the ITT margin at that time was 7°C.

The guidelines recommend PAC be conducted repeatedly at intervals of 250 flight hours when the ITT margin is less than 10°C. The serious incident occurred before the 250-flight-hour interval was reached as counted from July 13 when the Company conducted PAC.

The information described in 2.12.1 (8) is guidelines that the engine manufacturer provides to the operators as an aid for planning the troubleshooting schedule, so following it is not mandatory. However, it is considered desirable that the Company, who was aware of this guideline, would have carried out appropriate maintenance service within the appropriate flight hours considering possible deterioration of the hot section as suggested by the notification from the ECTM analysis company.

As described in 2.12.1 (8), the engine manufacturer indicated as guidelines the specific actions to take and the period within which they should be taken when the operator recognizes an engine status change from ECTM data, but did not include the information in the AMM. Since ECTM is an effective source of information for identifying the extent of engine deterioration and for planning a maintenance schedule in an early stage, it is desirable that the manufacturer gives consideration for enabling operators to properly perform appropriate actions based on it, such as by clearly indicating the relevant information in the AMM rather than providing the information merely as guidelines.

As described in 2.5.3, the Company conducted PAC on July 13, 2008 and found the ITT margin to be 7°C. According to the FIM described in 2.12.1 (4), the FIM task is "closed out" (terminated) if no fault is found in the PAC fault confirmation process, without the need for proceeding to fault isolation. Since the ITT margin was 7°C, not less than 5°C below the maximum limit as described in 2.12.1 (3), it is considered probable that the Company determined that the PAC found no fault and closed out the FIM task described in 2.12.1 (4) without proceeding to the fault isolation step shown in Figure 201.

However, if the trend in ECTM data changes as described in 2.10 is applied to Figure 201 of the FIM described in 2.12.1 (4), then the figure suggests HP turbine problem of the No. 1 engine as the probable defect and recommends BSI as the action to take. Since it is considered possible that deterioration of the HPT shroud or LPT vane segments would have been found if BSI was conducted at that time, it is considered necessary for the engine manufacturer to review the FIM so that defects may not be left unconfirmed during the FIM fault confirmation procedure described in 2.12.1 (4).

3.7 Red ITT Display

It is considered highly probable that, while the maximum ITT reached during takeoff on flight JAC2419 of

August 11, 2008 was 861°C and thus the ITT display in the cockpit turned red, the maintenance engineer who carried out inspection did not take any action in accordance with the AMM, which states that no actions are required below 880°C as described in 2.12.1 (1). It is also considered highly probable that, while the maximum ITT reached during takeoff on flight JAC3647 of August 12, 2008 read 856°C causing the display to turn red, no actions were taken as the ITT was below 880°C as with the flight of the previous day.

It is considered highly probable that the Company had decided before the occurrence of the serious incident on August 12, 2008 on a plan for replacing the No. 1 engine after the Aircraft's last flight on August 13, 2008, as described in 2.1.1 (4), considering these facts: the ITT display for the Aircraft's No. 1 engine had turned red on August 11 and 12, 2008 and the PAC conducted on July 13, 2008 on the No. 1 engine showed an ITT margin as small as 7°C.

There is a difference between the ITT at which the cockpit ITT display turns red (845°C for approximately 34°C OAT at which the serious incident occurred) during NTOP power setting as described in 2.12.1 (7) and the engine operating limit (no actions required below ITT 880°C) as described in 2.12.1 (1). However, no actions to take are specified for the situation in which the ITT display turns red but the ITT is below 880°C as in this serious incident. It is desirable that the engine manufacturer and the aircraft design/manufacturing company revise the relevant manuals to ensure consistency among them so that operators can properly identify the maintenance actions to take when problems arise.

4. PROBABLE CAUSE

It is considered highly probable that this serious incident occurred through the following series of events: During the Aircraft's takeoff roll, the inner drum of an LPT vane segment in the No. 1 engine fell off and was caught across the space where the LPT rotated, which caused damage to the rotating LPT blades and the resulting debris further damaged the inter-turbine vane, the 1st and 2nd stage PT blades and the PT vane that were located downstream from it.

It is considered highly probable that the inner drum of the LPT vane segment fell off because the four vane airfoils constituting the vane segment were fractured due to deterioration and the deterioration of the LPT vane occurred and progressed along with the deterioration of the HPT shroud located upstream from the LPT vane.

5. REFERENTIAL MATTERS

5.1 Actions taken by the Company

The Company requested that the engine manufacturer revise the AMM with regard to points (1) to (3) below, and also issued the Company's AMM Bulletins dated September 30, 2008 on the following points, based on the results of the engine disassembly investigation and the Service Information Letters and Service Bulletins issued by the engine manufacturer after the serious incident.

(1) AMM Task 05-11-00-992-802 (engine time limits, operating limits and leading particulars) requires no maintenance actions when the ITT is below 880°C. Notwithstanding this, the Company clarified the actions to take (PAC and FIM tasks) when the ITT display turns red while the ITT is below 880°C in order to ensure that preventive maintenance actions are taken.
Subsequently, the engine manufacturer requested that the aircraft design/ manufacturing company revise the AMM to be described in 5.2.

(2) After being informed by Service Information Letters and Service Bulletins that no specific descriptions on HPT shroud inspection are given in AMM Task 72-50-00-280-801 (Special Detailed Inspection of the Turbine Gas Path Components) and AMM Task 72-40-00-280-801 (Special Detailed Inspection of the Combustion Chamber Liner Components), the Company instructed its maintenance staff through Company AMM Bulletins to ensure that BSI on the HPT shroud is performed when conducting these AMM Tasks.

(3) As the ECTM alert criteria were provided by the engine manufacturer only as guidelines and were not included in AMM Task 72-00-00-890-804 (ECTM), the Company established the criteria and clarified the actions to take for each alert.
As described in 5.2, a temporary revision pages revising this AMM Task was issued.

(4) In order to validate the appropriateness of the BSI intervals for the hot section, i.e., 4,000 hours for the first inspection and thereafter every 1,500 hours, and investigate the possibility of sudden progress in deterioration of the hot section, the Company established additional actions (overall inspection at every repeated inspection, etc.) to be performed on the hot section of specific engines that is placed under follow-up monitoring.

5.2 Actions taken by the Engine Manufacturer and the Aircraft Design/ Manufacturing Company

The engine manufacturer requested the aircraft design/manufacturing company to revise the contents of AMM Tasks and FIM Task including matters relating to this serious incident. In response to this, the aircraft design/manufacturing company took actions to add the ECTM alert criteria, to revise the procedures for PAC, to revise the measures for engine over temperature, to revise the procedures of fault isolation for performance deterioration or trend shift, to revise the procedures for BSI and so on by issuing following Temporary Revisions sequentially: TR72-043, TR72-045, TR72-046, TR05-092, TR72-050, TR71-003, TR71-122, TR72-051 and TR72-052.

Figure 1 Estimated Route followed by the Aircraft

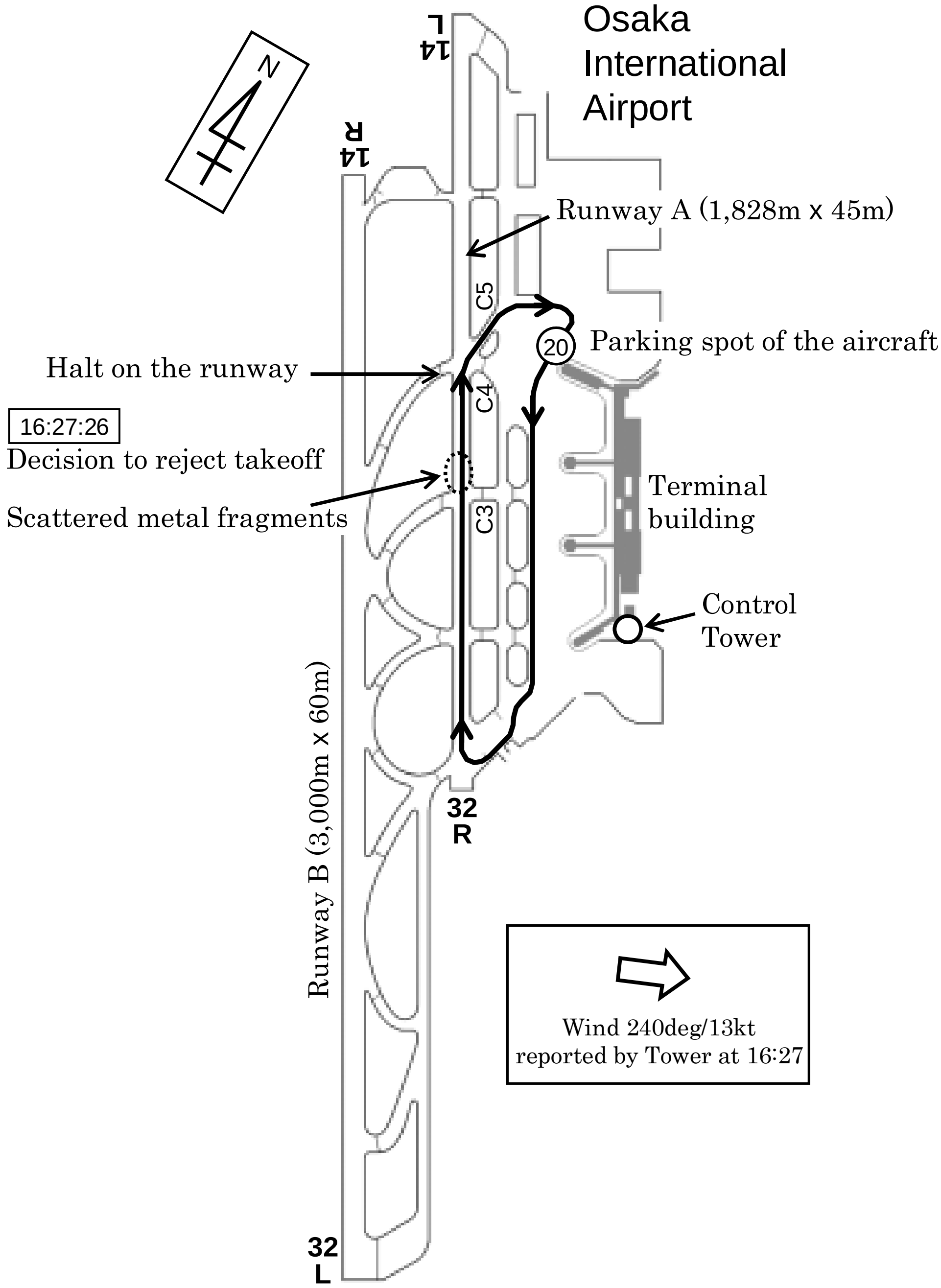
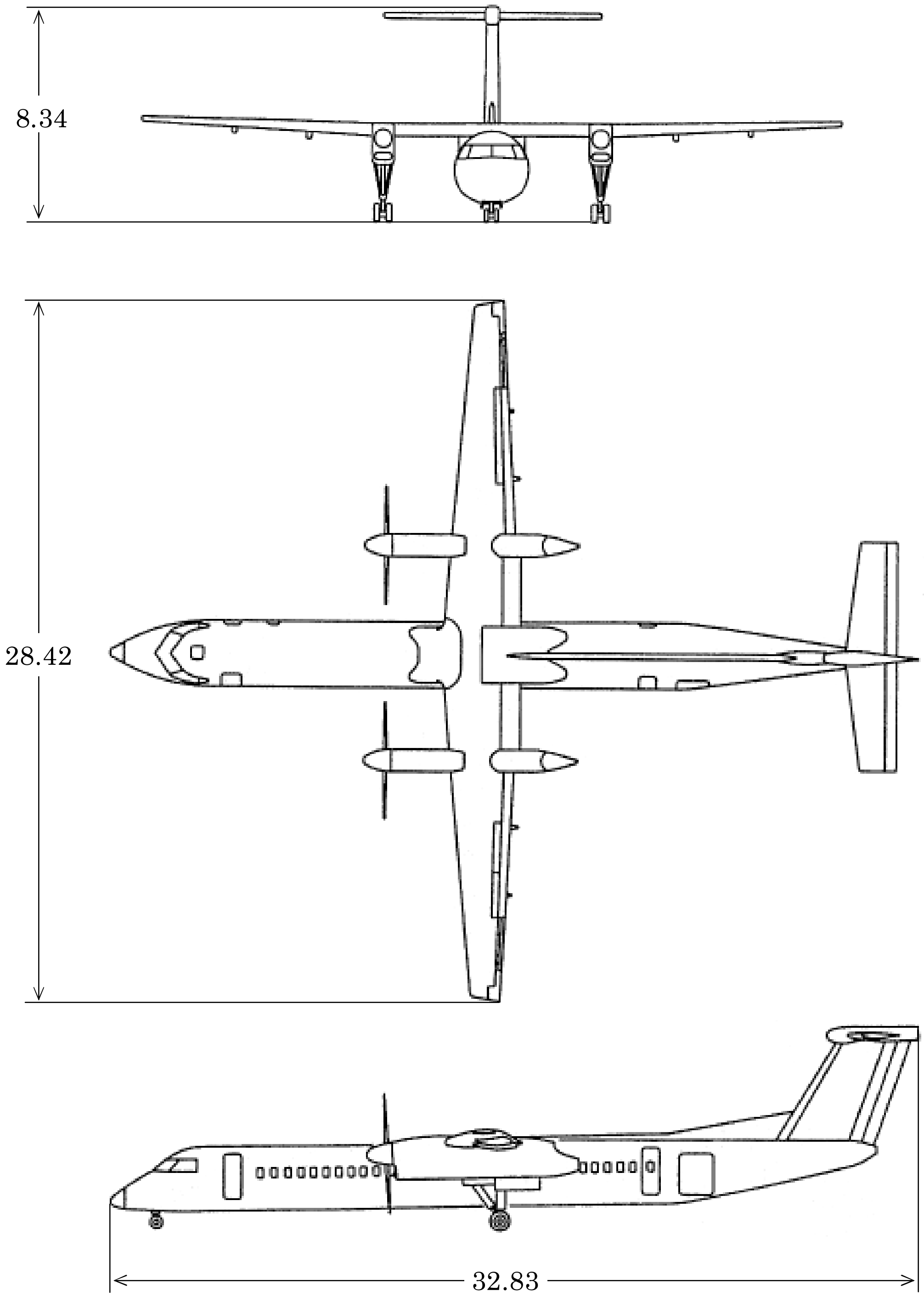


Figure 2 Three Angle Views of Bombardier DHC-8-402

Unit : m



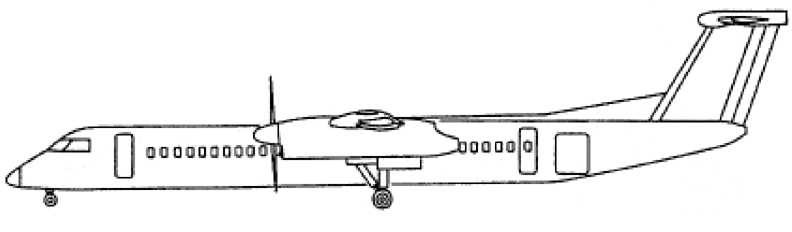
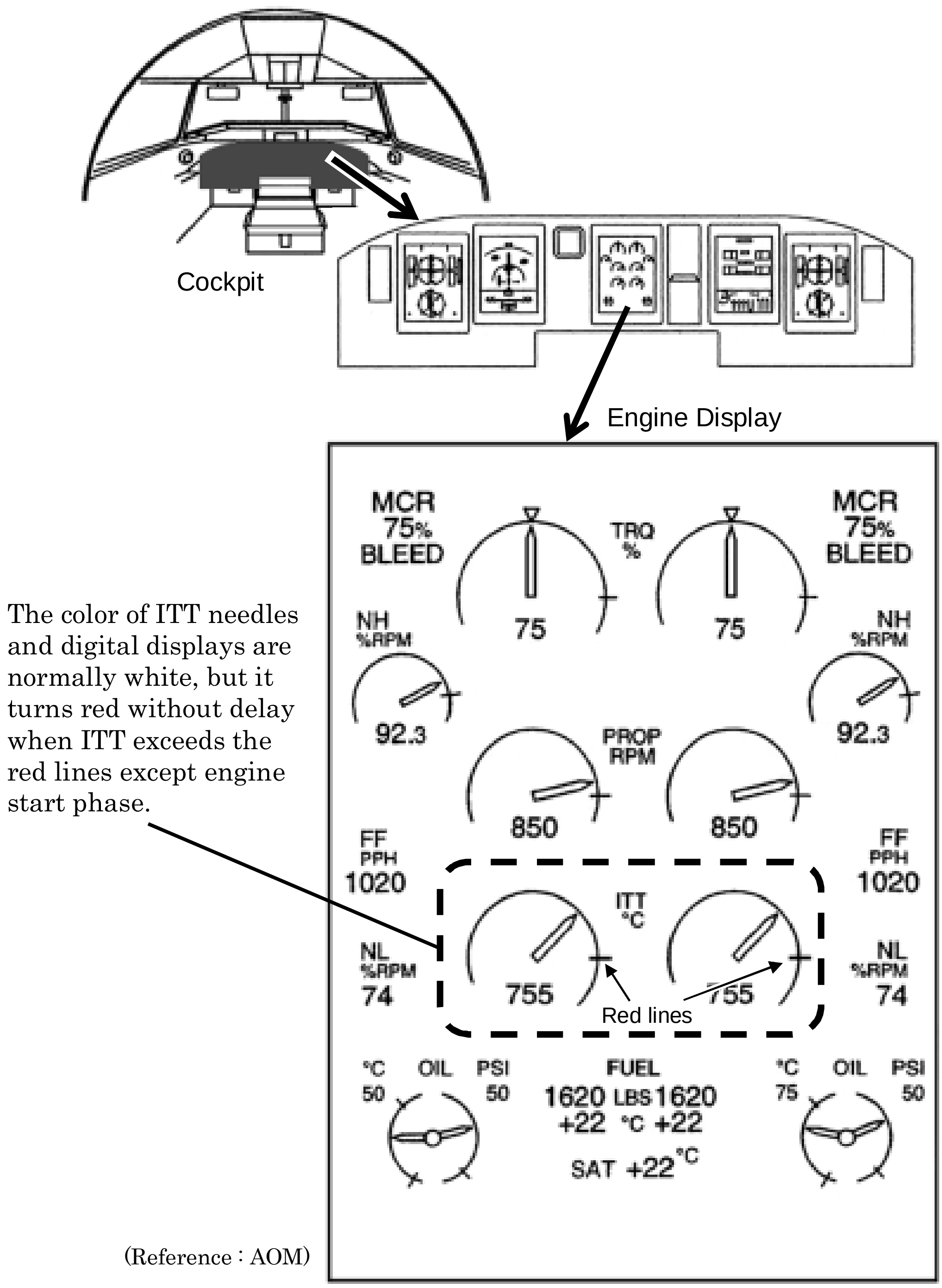
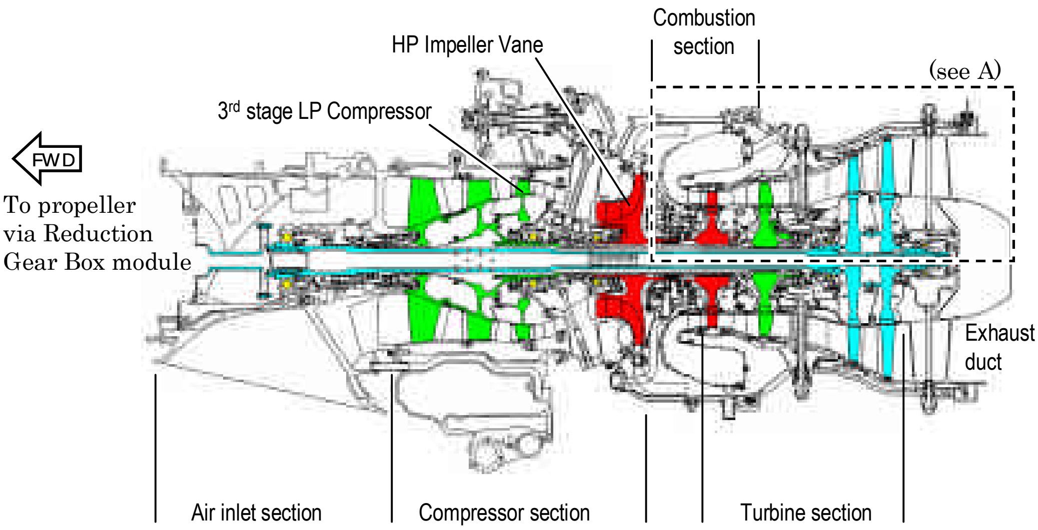


Figure 3　Engine Display



(Reference：AOM)

Figure 4　PW150A Engine



A

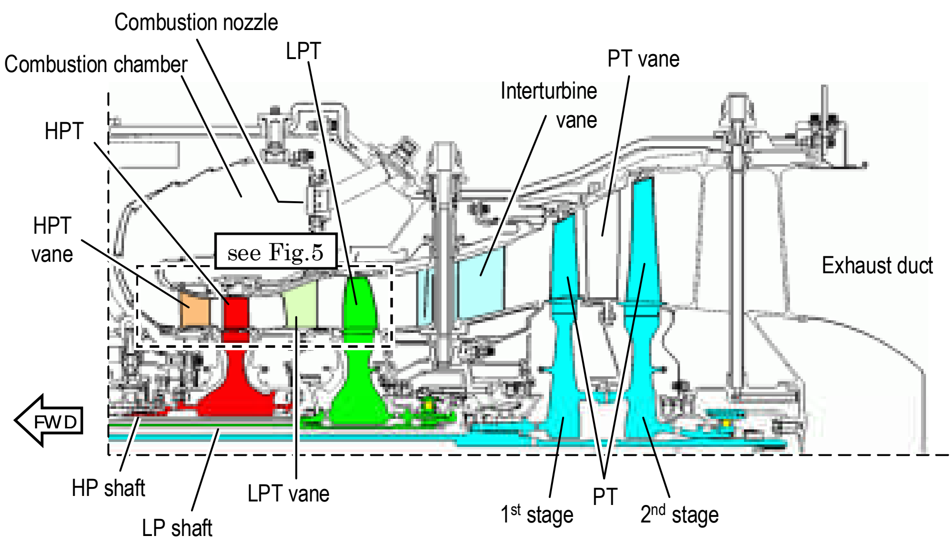
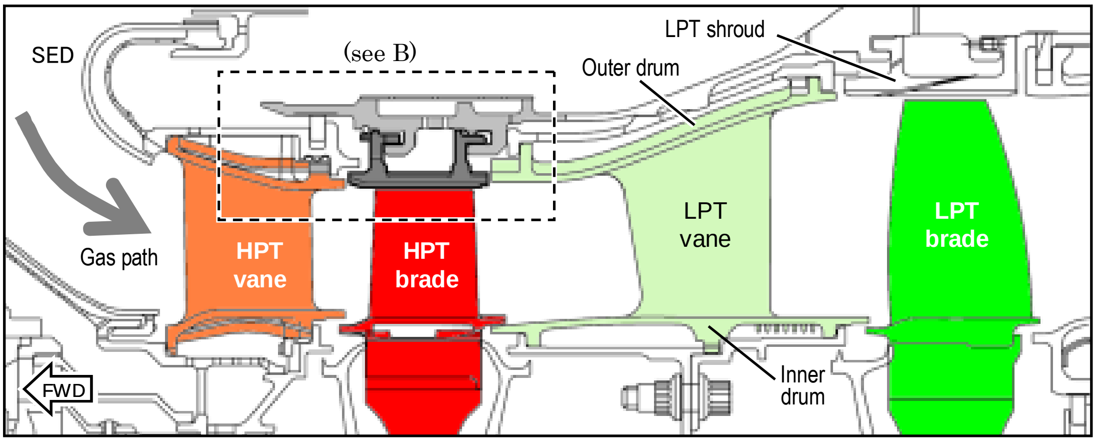
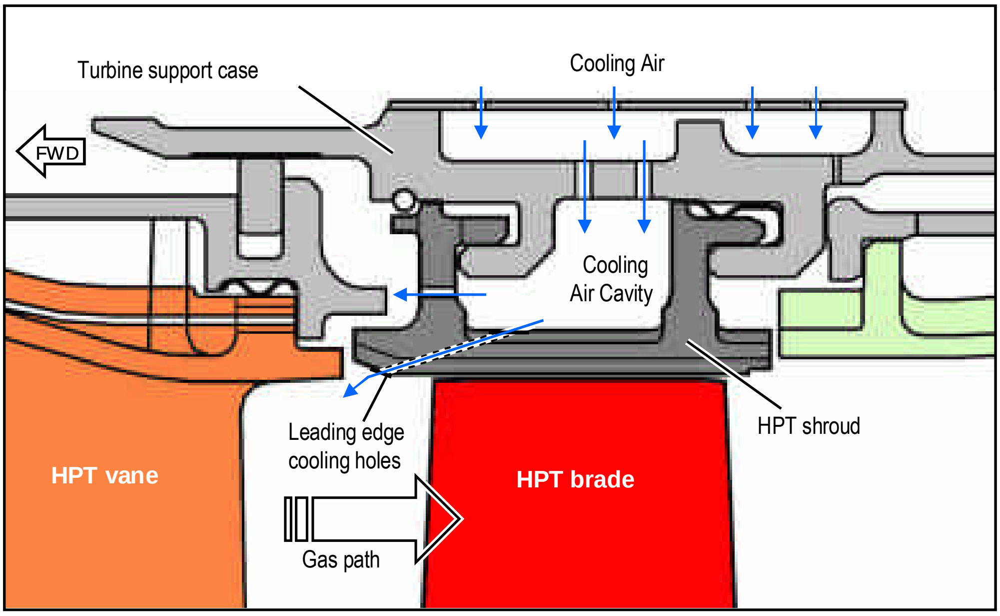


Figure 5　HPT and LPT

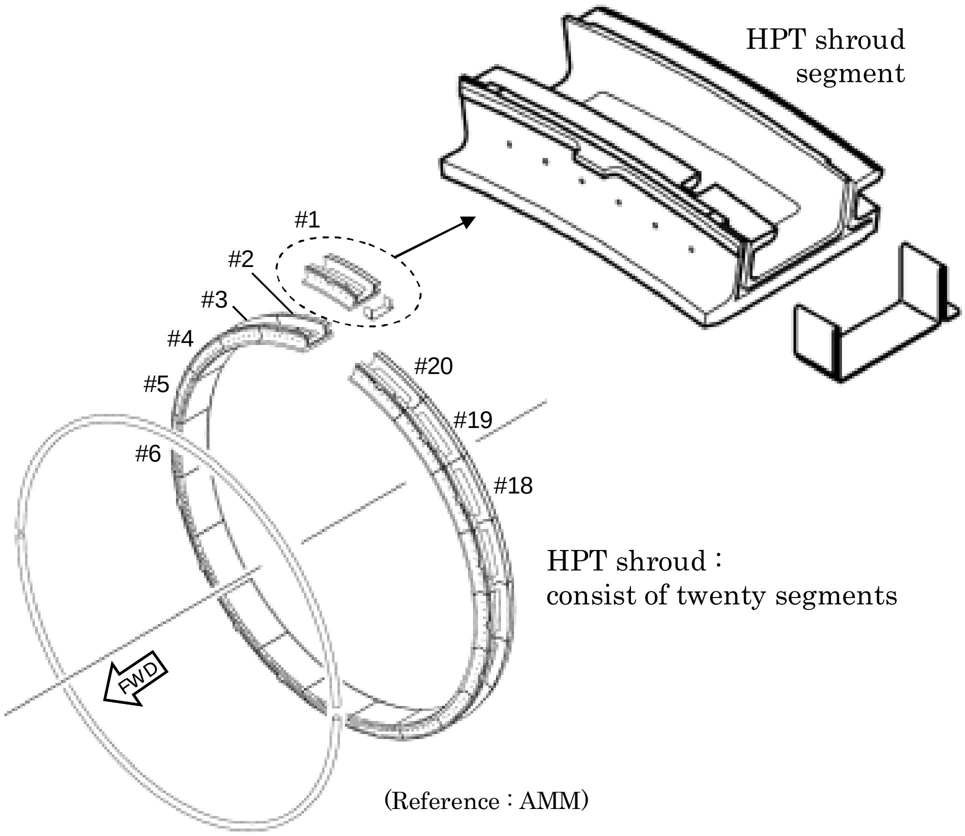


B：HPT Shroud



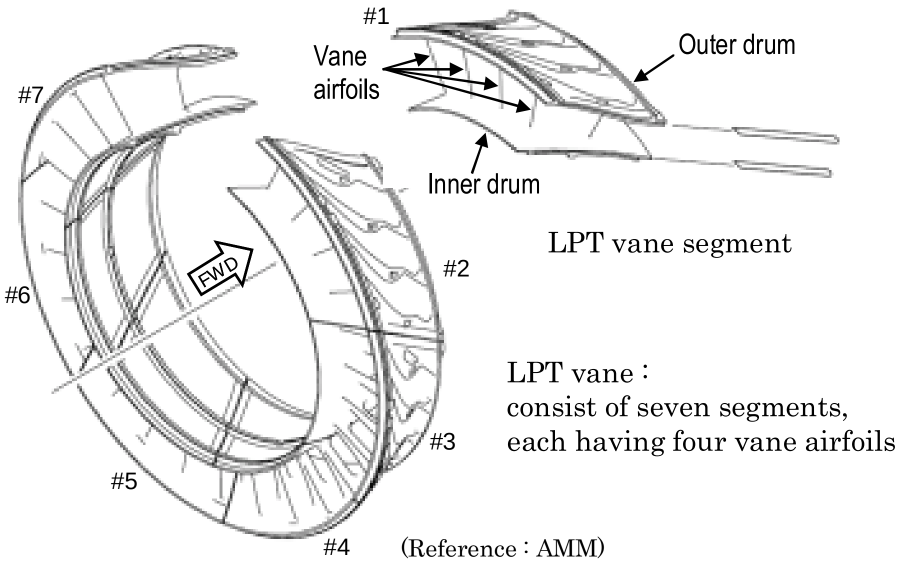
(Reference : AMM)

Figure 6　HPT Shroud Segment



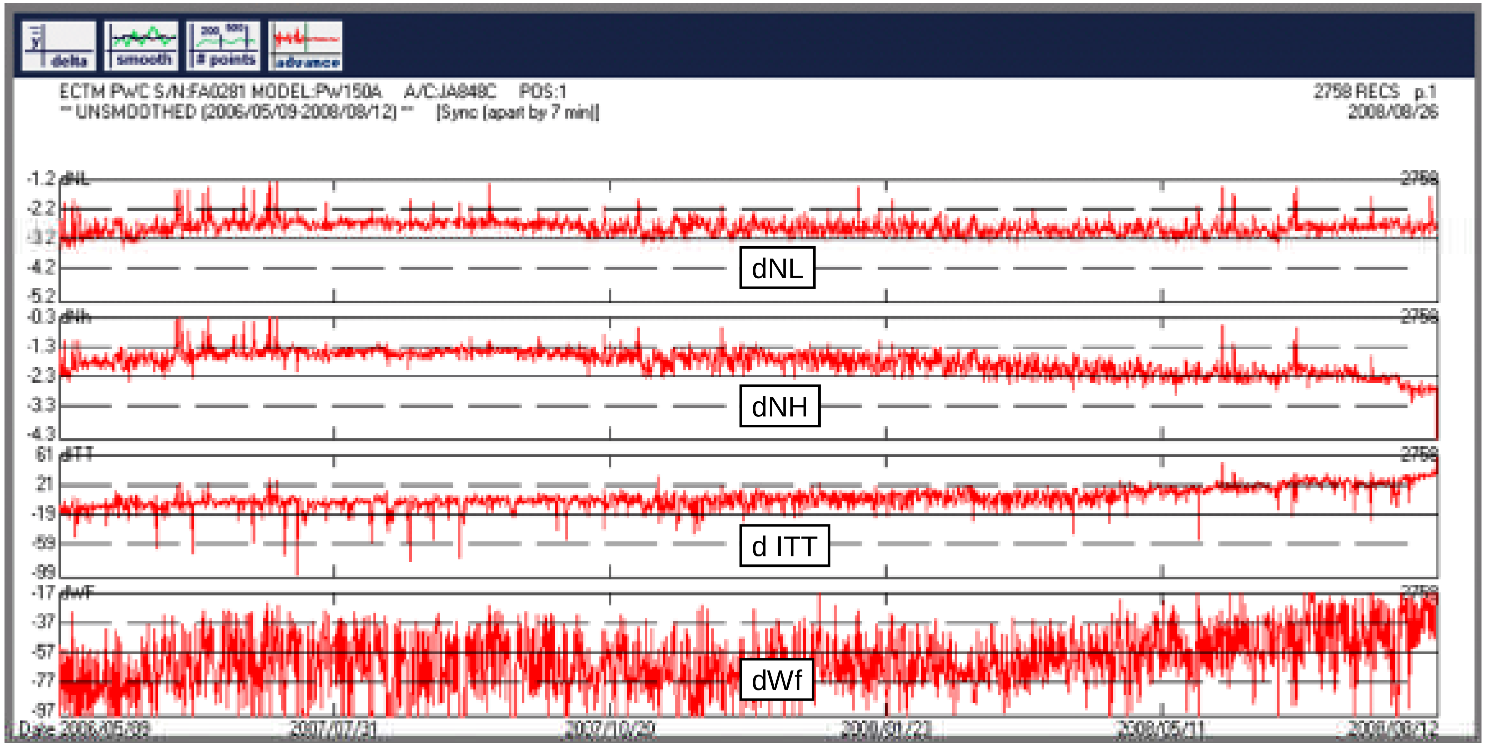
(Reference：AMM)

Figure 7　LPT Vane Segment



(Reference：AMM)

Figure 8 ECTM Graphs



Note : "d" means the difference from the each reference values, NL (LP compressor speed), NH (HP compressor speed), ITT (Inter-turbine Temperature) and Wf (Fuel Flow).

Figure 9   DFDR Records

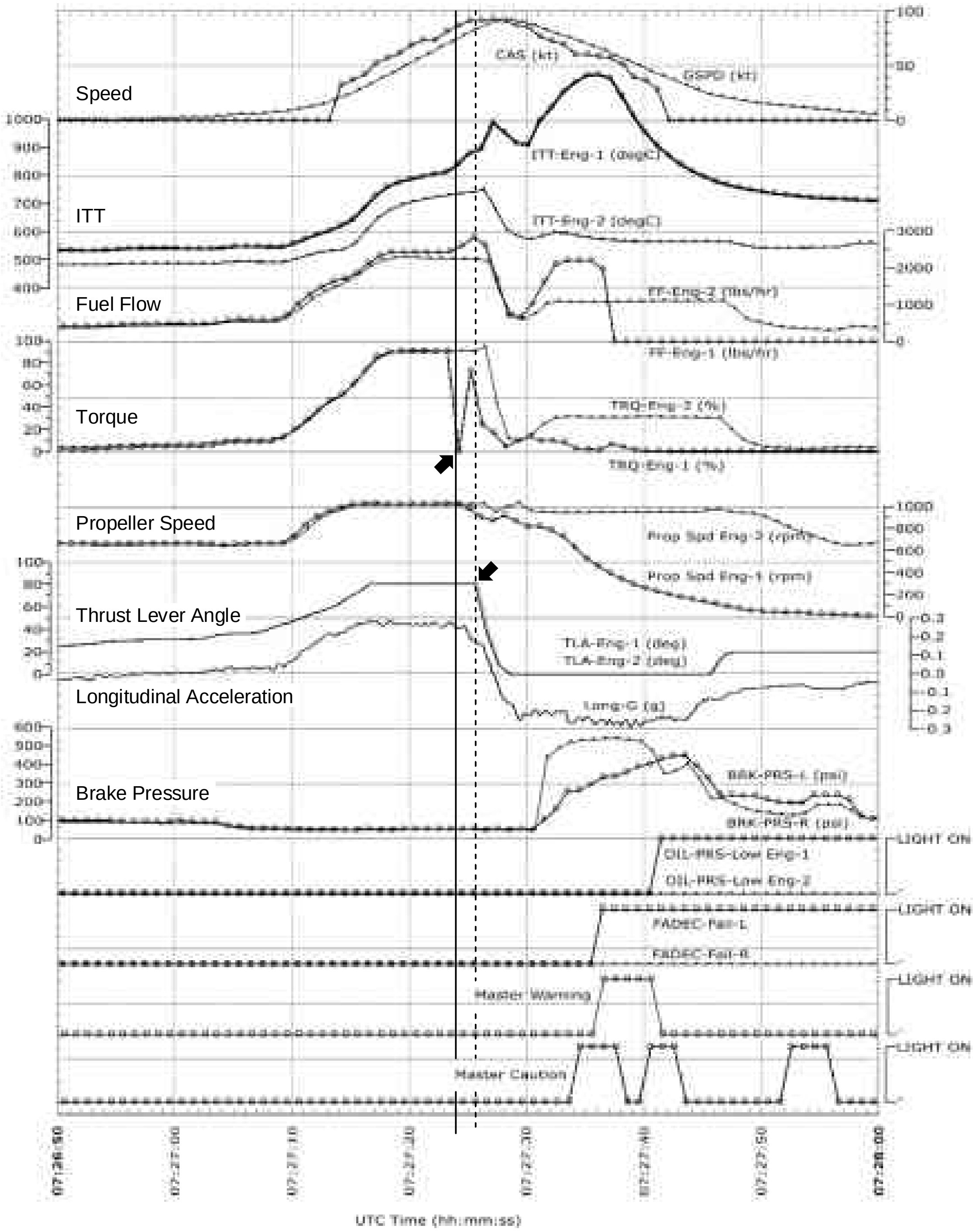


Photo 1　Serious Incident Aircraft

Photo 2　SED and HPT vane (BSI view)

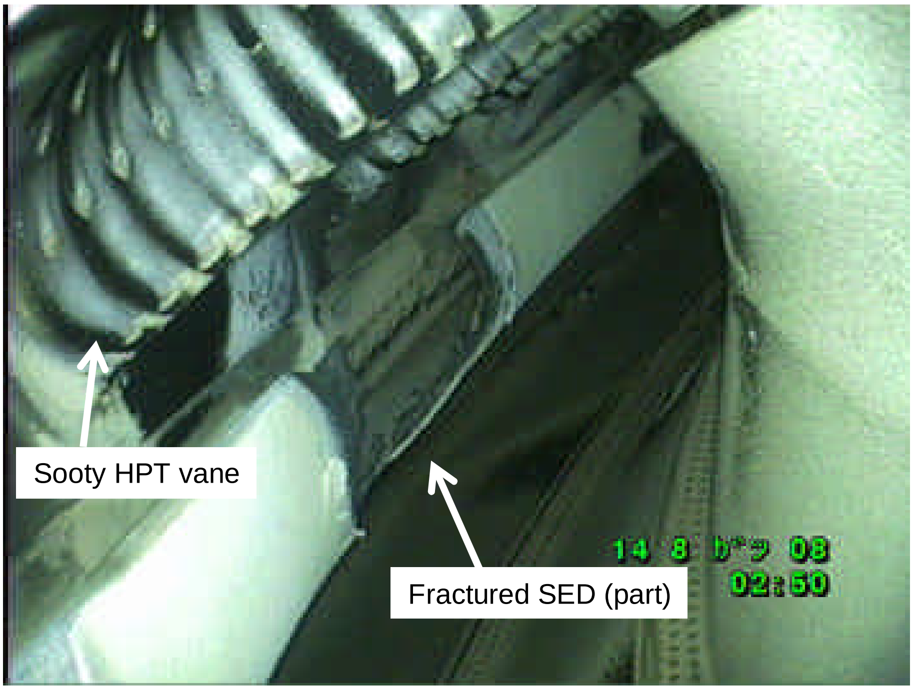


Photo 3 HPT blades (BSI view)

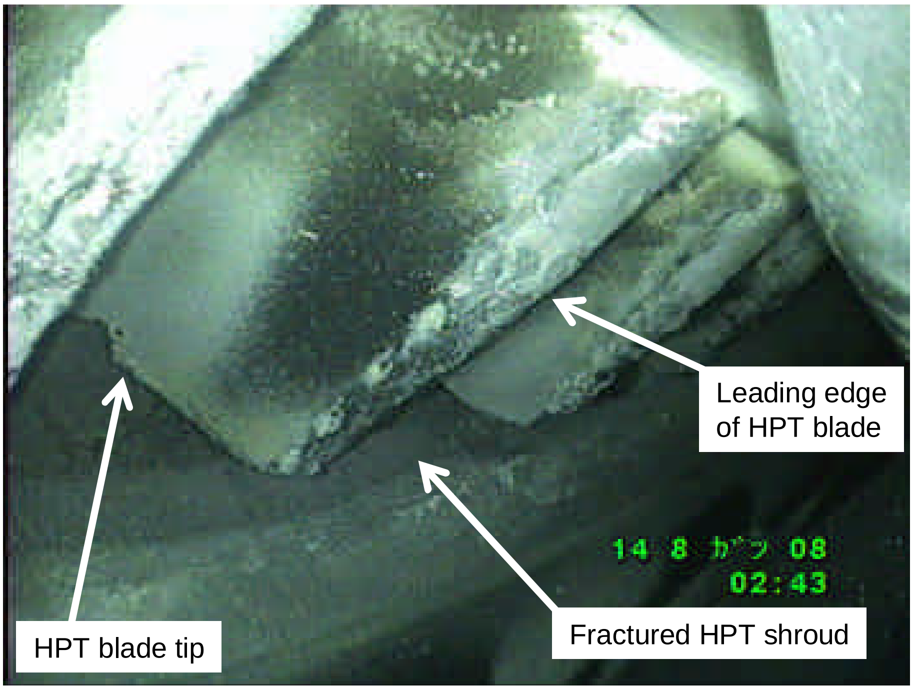


Photo 4 HPT shroud (BSI view)

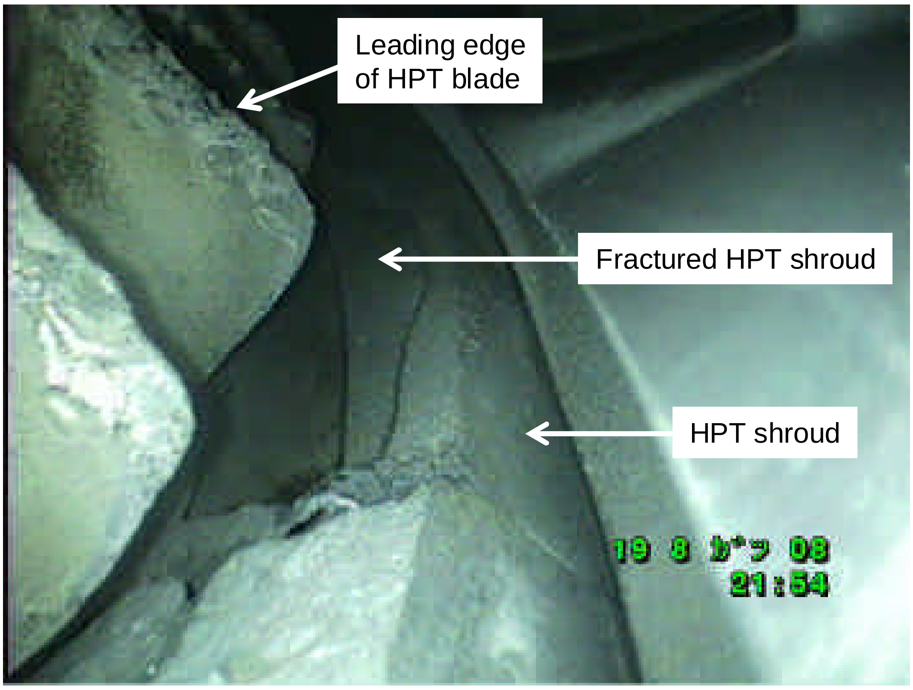


Photo 5　LPT vane segment (BSI view)

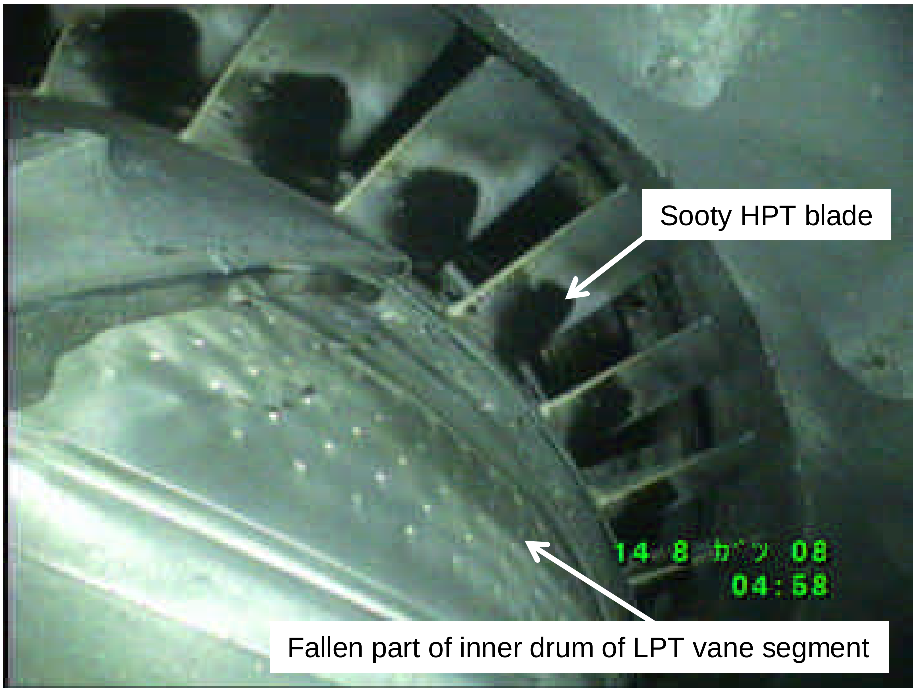


Photo 6　Fractured LPT vane airfoils (BSI view)

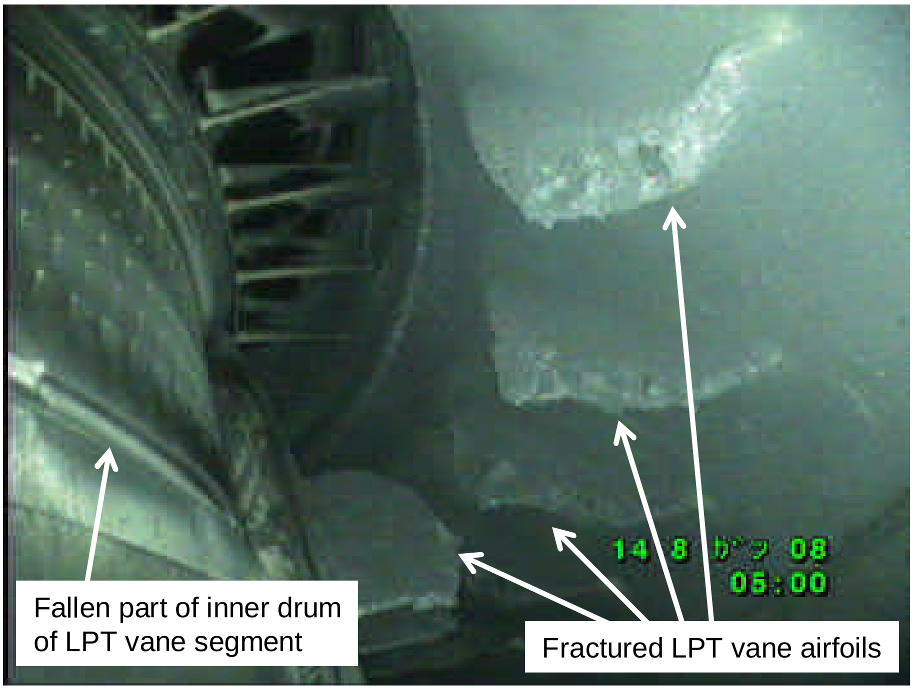


Photo 7　　Deteriorated LPT vane airfoil (BSI view)

Photo 8　　LPT blades (BSI view)

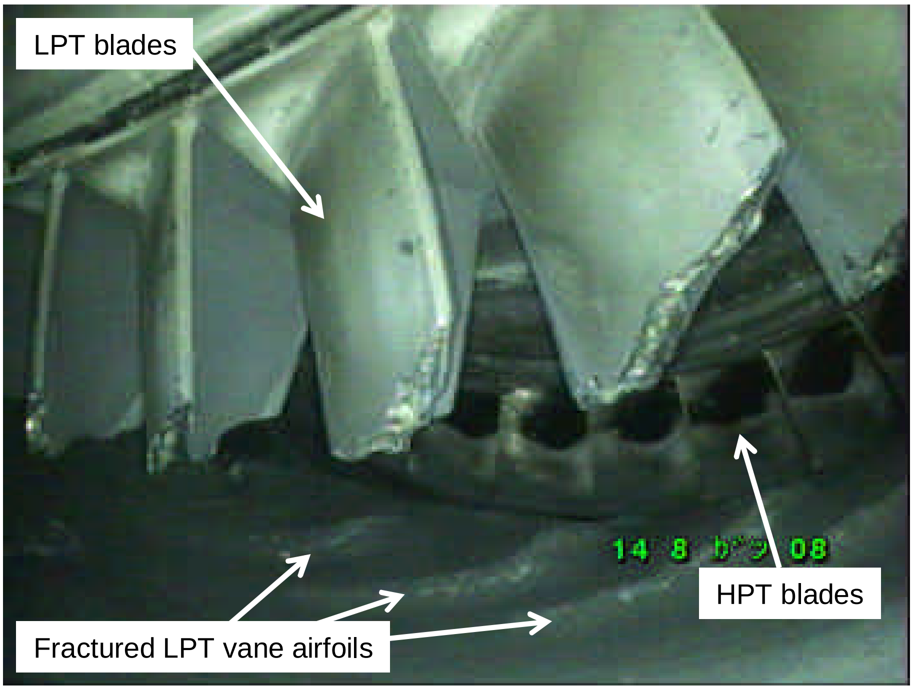


Photo 9 Fallen inner drum of LPT vane segment – the end trapped in LPT vane (BSI view)

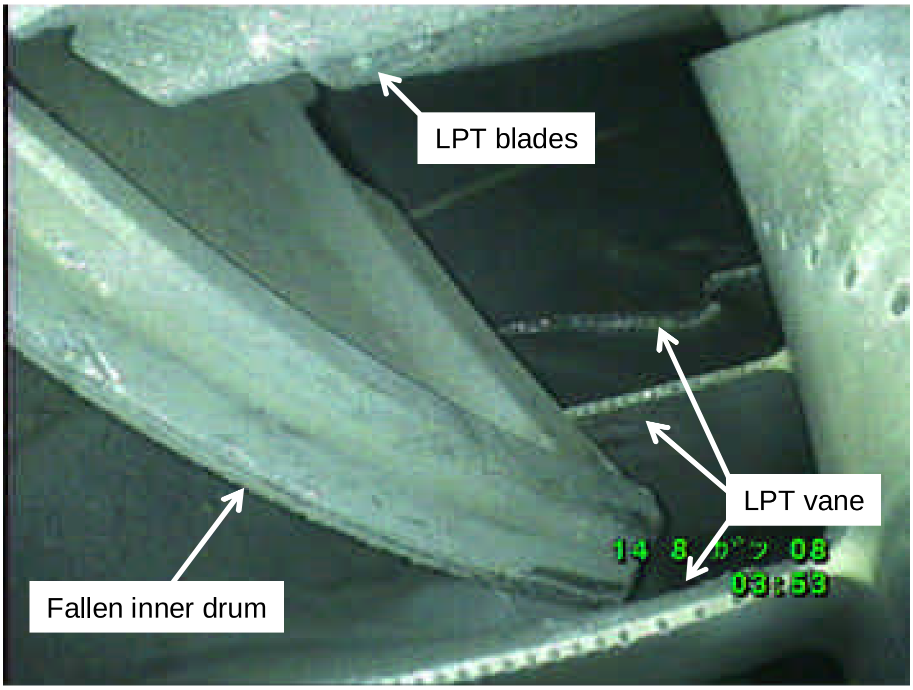


Photo 10 Fallen inner drum of LPT vane segment –the end trapped in inter-turbine vane (BSI view)

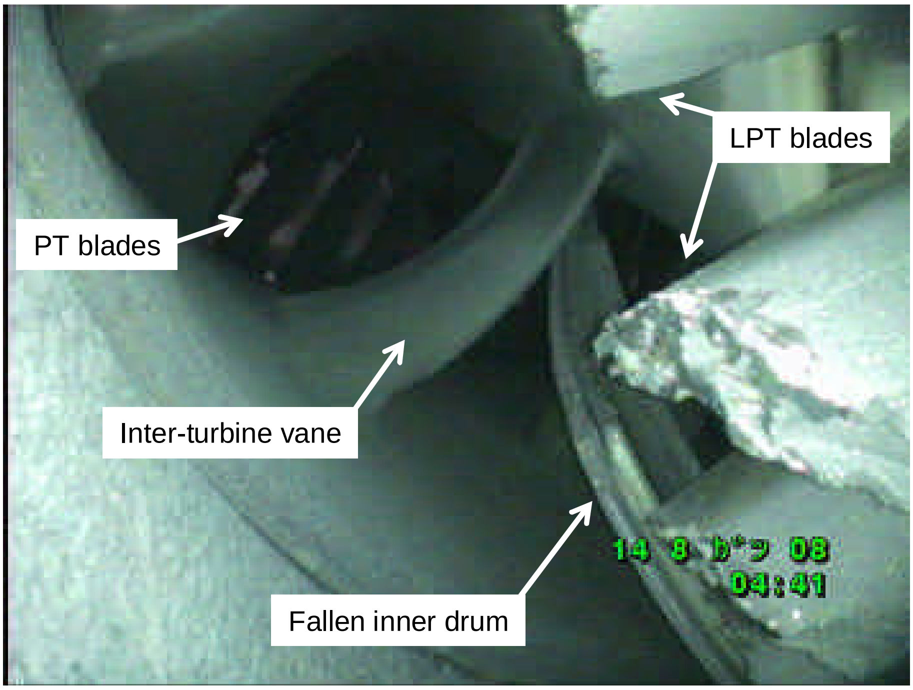


Photo 11 PT blades and PT vane airfoils (BSI view)

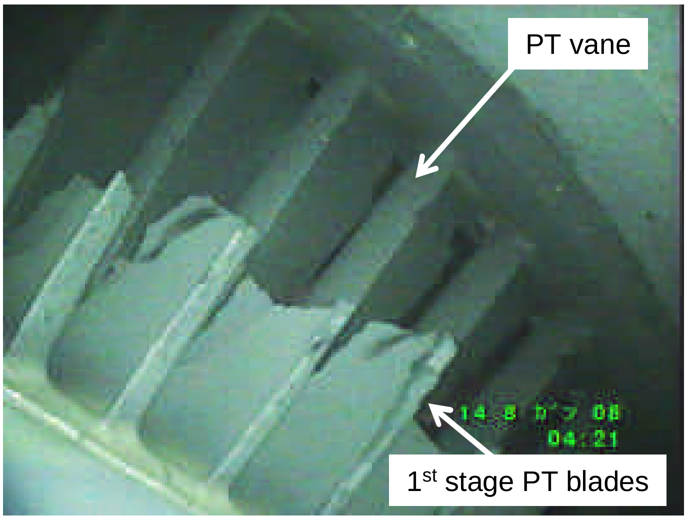


Photo 12 2nd stage PT blades

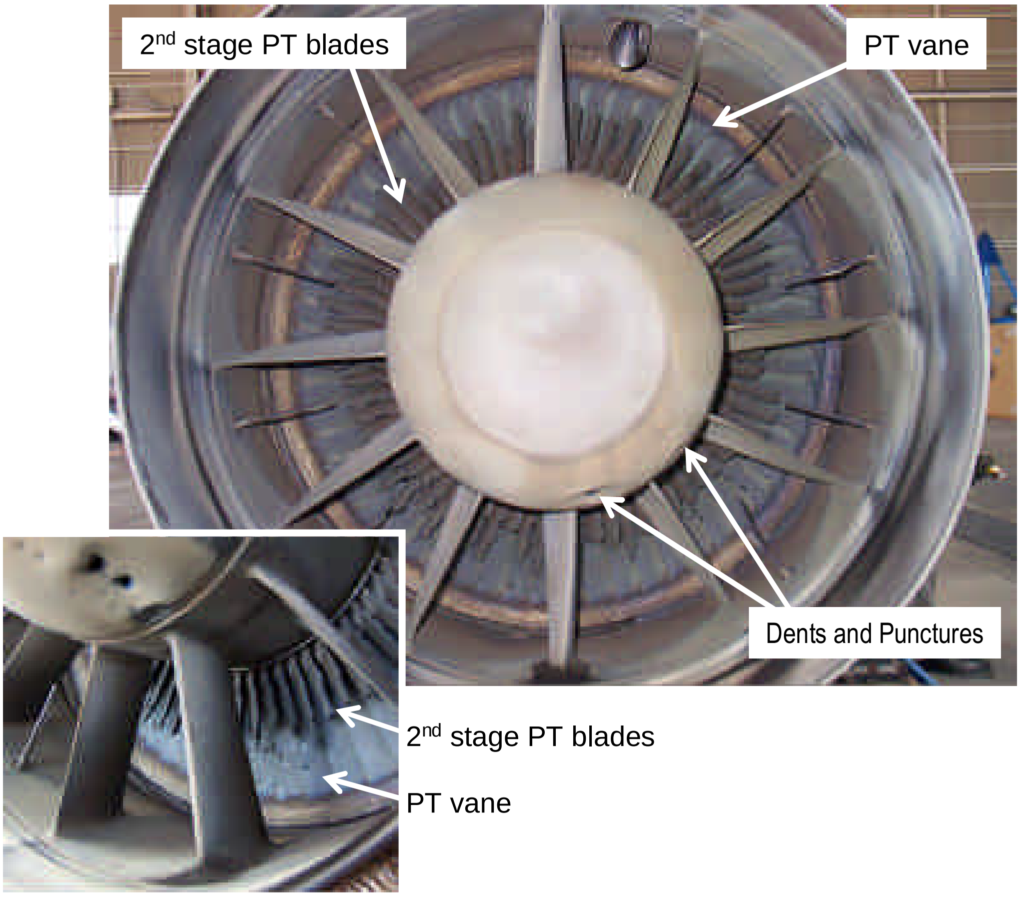
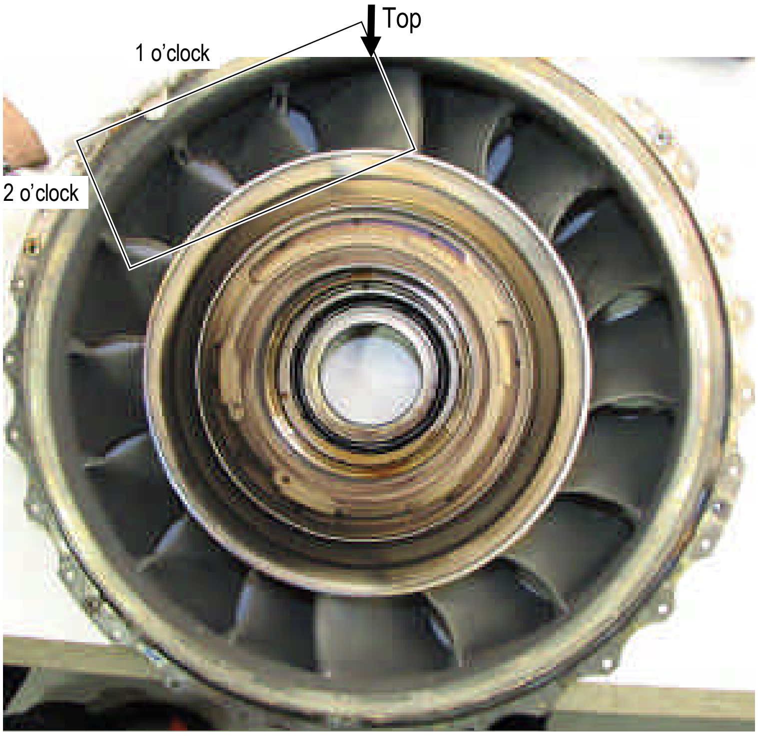


Photo 13 Inner drum of LPT vane segment trapped in inter-turbine vane

Inter-turbine vane (trailing edge side)

Photo 14 Inter-turbine vane – leading edge side



Heat erosion of inter-turbine vane airfoils

Photo 15　LPT disc

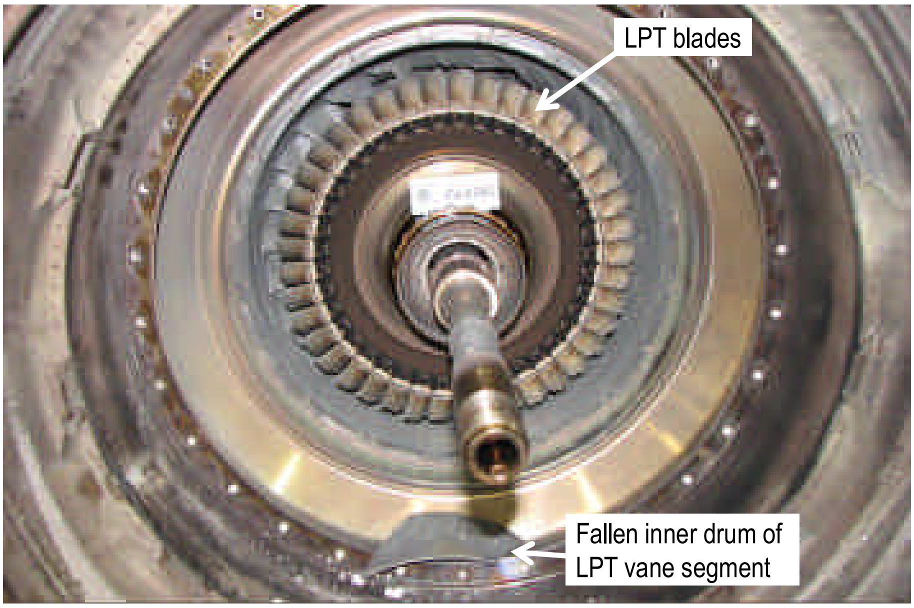


Photo 16　Damage to LPT blades and LPT vane airfoils

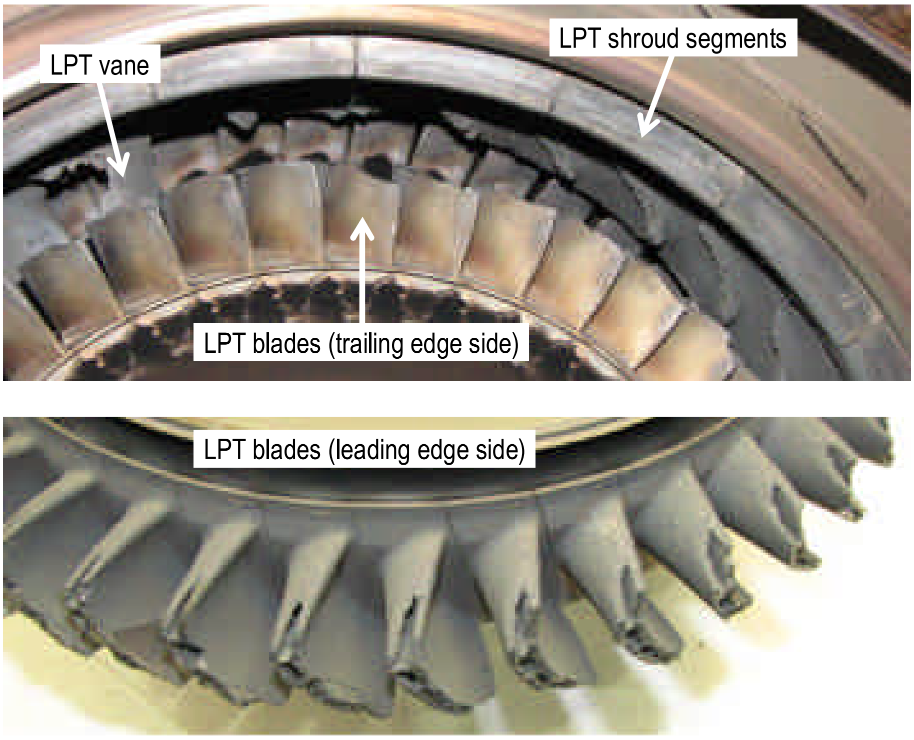


Photo 17　LPT shroud segments

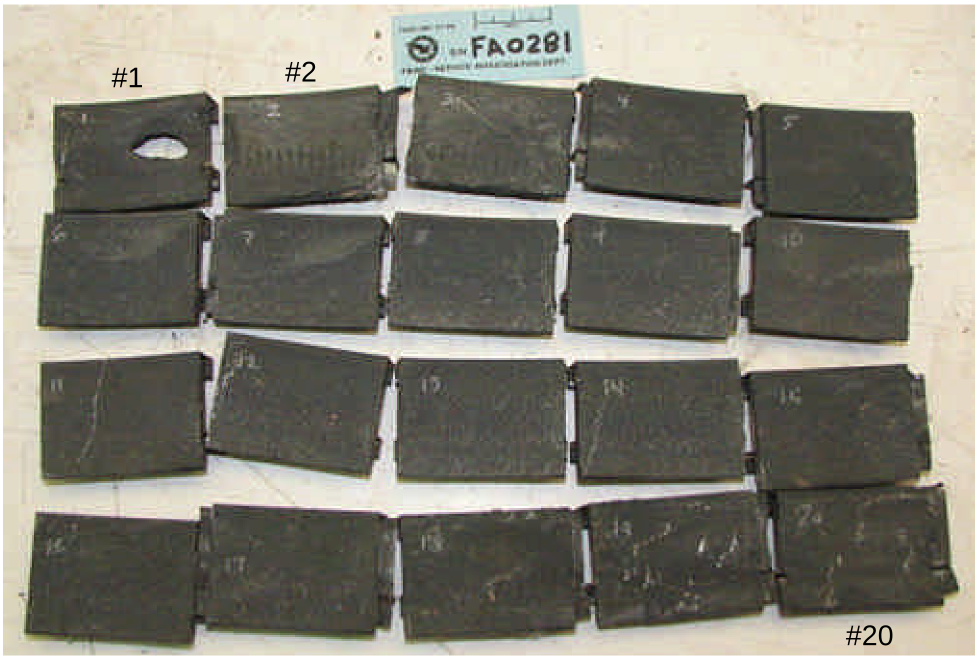


Photo 18　Fallen inner drum of #2 LPT vane segment

Gas path side　　Cooling cavity side

Photo 19 LPT vane – leading edge side

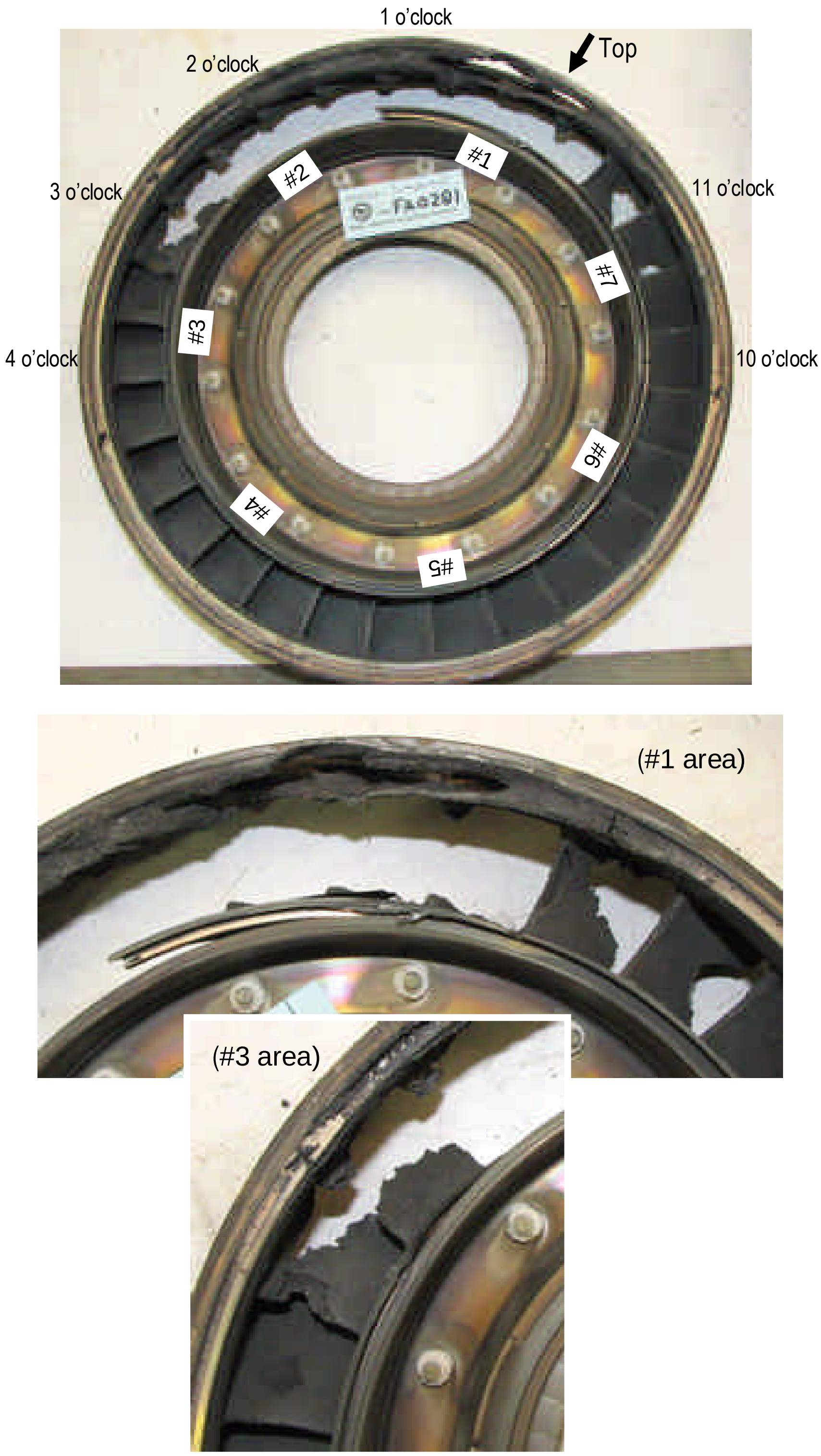


Photo 20　LPT vane segment – new segment

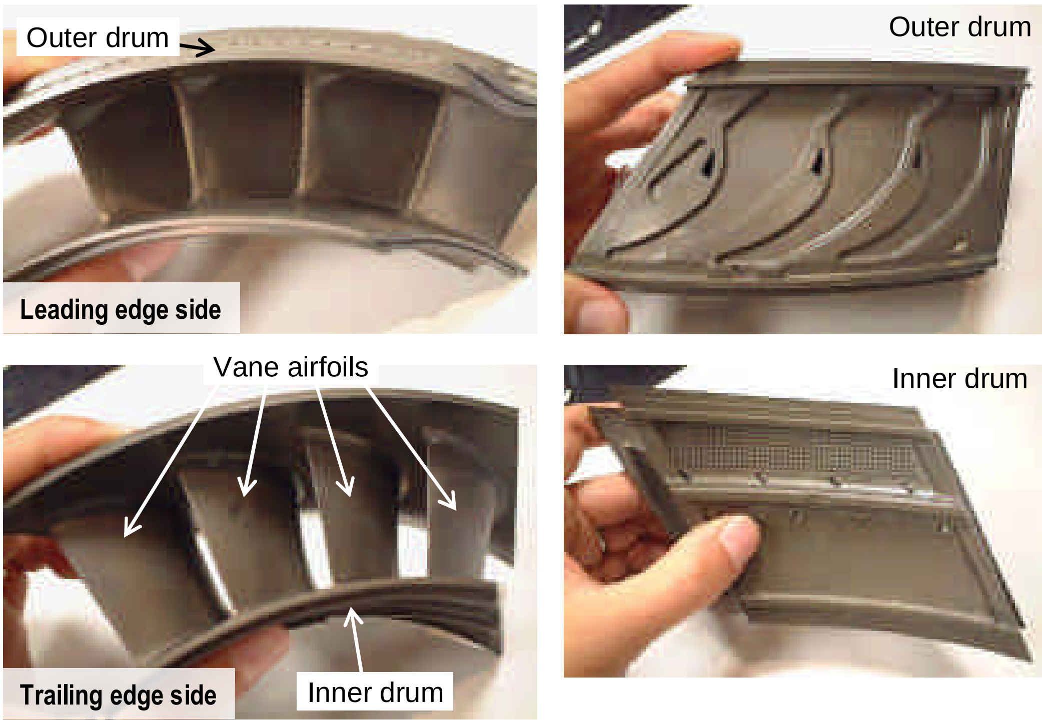


Photo 21　Damage to HPT shroud

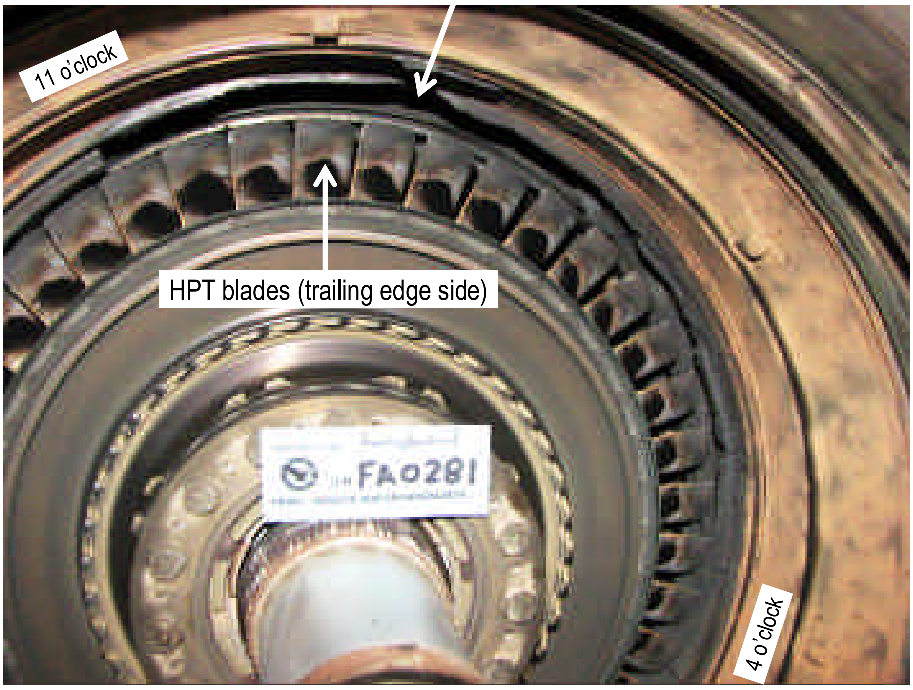


Photo 22 HPT disc – leading edge side

Photo 23 HPT blades

Photo 24 HPT shroud

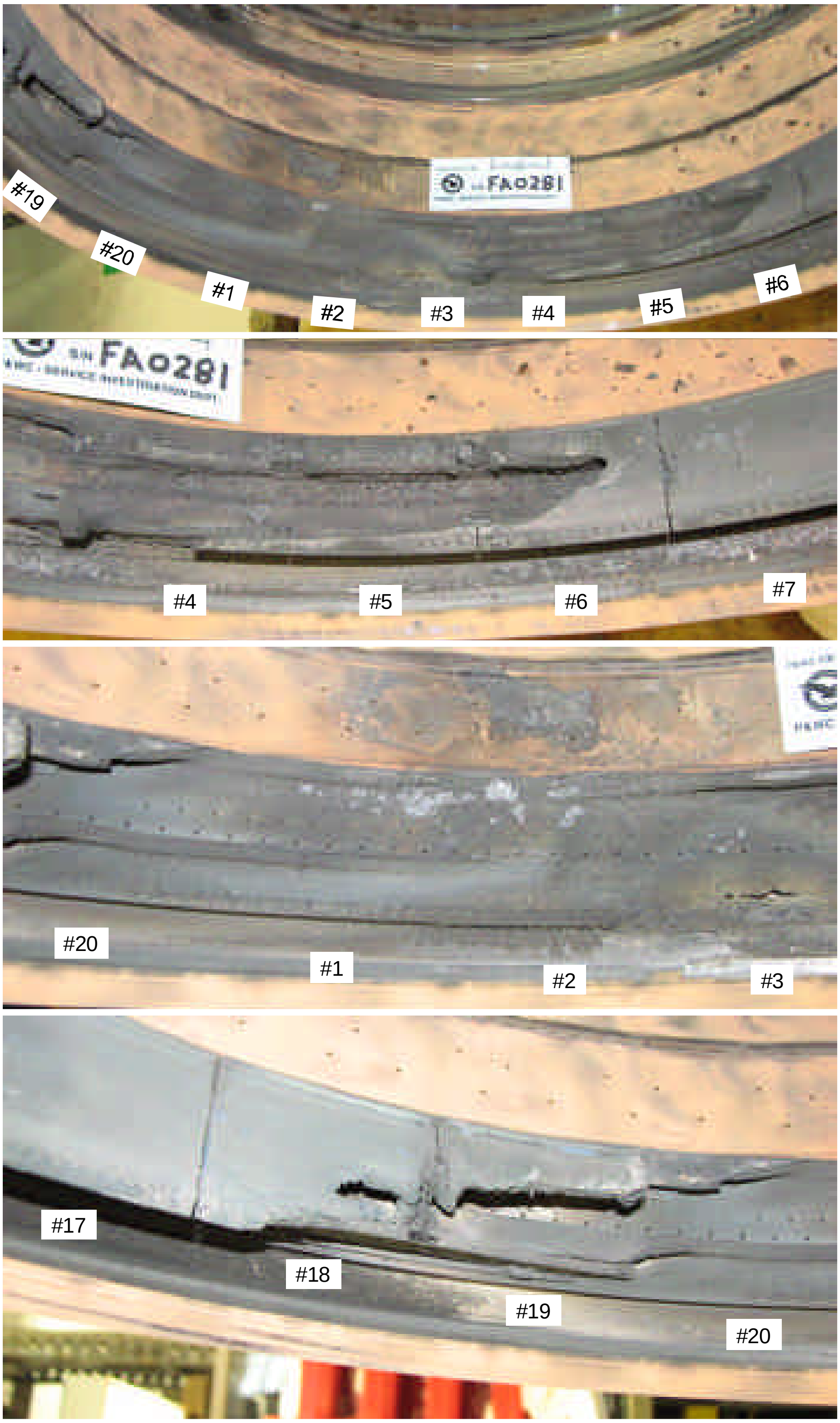


Photo 25 HPT shroud segments

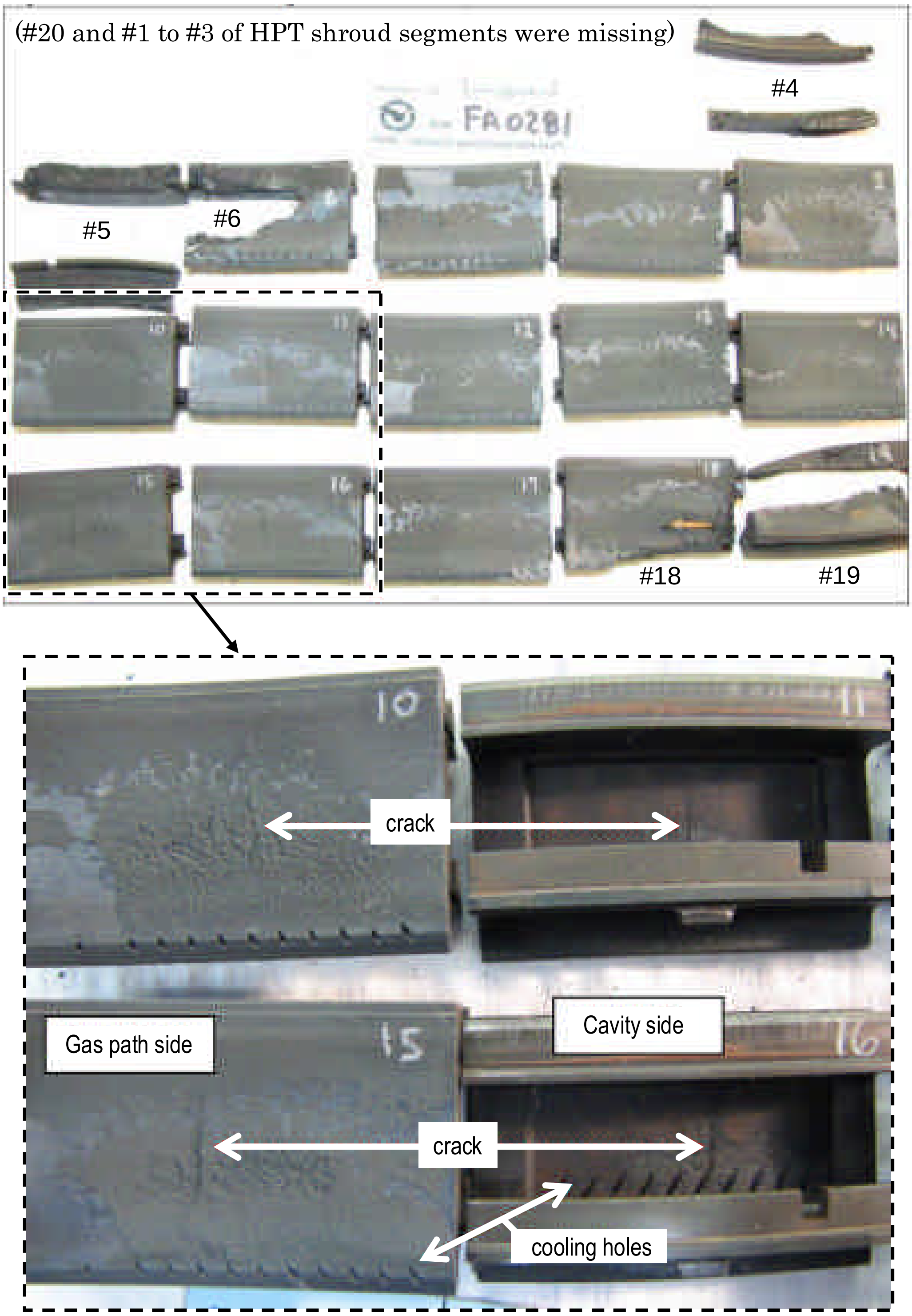


Photo 26 HPT shroud segment – new segment

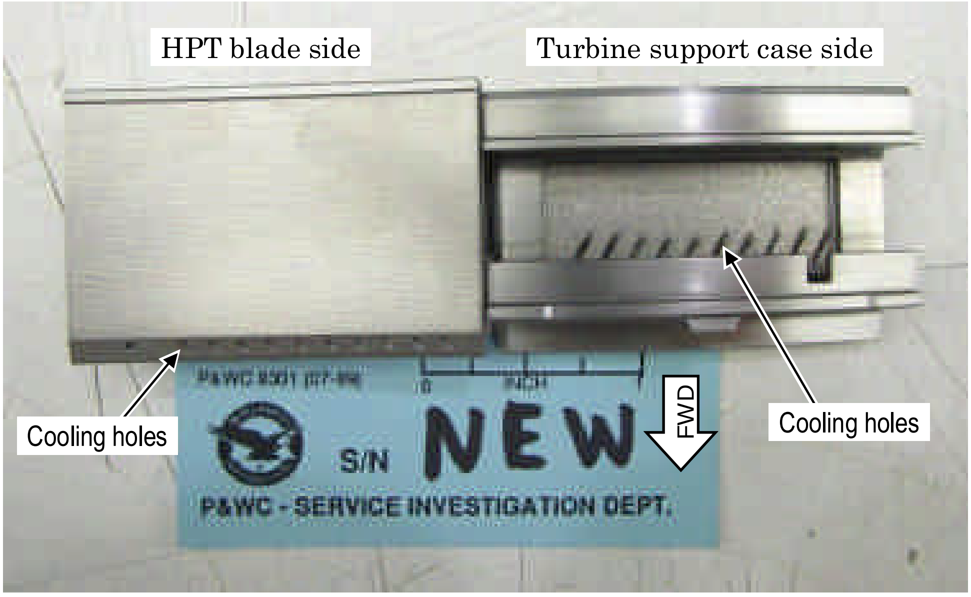


Photo 27 SED