AI2012-1

AIRCRAFT SERIOUS INCIDENT INVESTIGATION REPORT

UNITED AIRLINES

N 2 1 9 U A

January 27, 2012

Japan Transport Safety Board

The objective of the investigation conducted by the Japan Transport Safety Board in accordance with the Act for Establishment of the Japan Transport Safety Board (and with Annex 13 to the Convention on International Civil Aviation) is to prevent future accidents and incidents. It is not the purpose of the investigation to apportion blame or liability.

Norihiro Goto
Chairman,
Japan Transport Safety Board

Note:

This report is a translation of the Japanese original investigation report. The text in Japanese shall prevail in the interpretation of the report.

AIRCRAFT SERIOUS INCIDENT INVESTIGATION REPORT

UNITED AIRLINES, INC.
BOEING 777-200, N219UA
AT ABOUT 11,700 FT, ABOUT 46 KM EAST-SOUTHEAST
OF NARITA INTERNATIONAL AIRPORT, JAPAN
AROUND 18:04 JST, JULY 28, 2010

December 16, 2011

Adopted by the Japan Transport Safety Board

Chairman	Norihiro Goto
Member	Shinsuke Endoh
Member	Toshiyuki Ishikawa
Member	Sadao Tamura
Member	Yuki Shuto
Member	Toshiaki Shinagawa

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 occurred inside the engine)” as stipulated in Clause 6, Article 166-(4) of the Civil Aeronautics Regulations of Japan, and is classified as a serious incident.

On July 28 (Wednesday), 2010, at 17:58 Japan Standard Time (JST; unless otherwise stated all times are indicated in JST, UTC+9hrs), a Boeing 777-200, registered N219UA, operated by United Airlines, Inc., took off from Narita International Airport for San Francisco International Airport on the company’s scheduled Flight 852. Around 18:04, while climbing above the sea about 46 km east-southeast of Narita International Airport, the aircraft’s right engine stalled. The aircraft then flew back to Narita International Airport and landed there at 18:46.

There were 270 persons on board: the Captain, two First Officers, 12 cabin attendants and 255 passengers. No one was injured.

1.2 Outline of the Serious Incident Investigation

1.2.1 Investigation Organization

On July 30, 2010, the Japan Transport Safety Board (JTSB) designated an investigator-in-charge and another investigator to investigate this serious incident.

1.2.2 Representatives from Relevant Authorities

An accredited representative of the United States of America, as the State of Registry, Operator, Design and Manufacture of the aircraft involved in this serious incident, participated in the investigation.

1.2.3 Implementation of the Investigation

July 30, 2010	Aircraft examination
August 12, 2010	Interviews
August 26, 2010	Engine teardown inspection
August 27, 2010	Interviews
September 13, 2010	Maintenance-related investigation
July 1, 2011	Engine detailed investigation

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

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

1.2.5 Comments from the Relevant State

Comments on the draft report were invited from the Relevant State.

2. FACTUAL INFORMATION

2.1 History of the Flight

At 17:58 on July 28, 2010, a Boeing 777-200, registered N219UA (hereinafter referred to as "the Aircraft"), operated by United Airlines, Inc. (hereinafter referred to as "UA"), took off from Narita International Airport (hereinafter referred to as "Narita Airport") as a UA scheduled Flight 852.

The flight plan for the Aircraft is outlined below:

Flight rules:	Instrument flight rules (IFR)
Departure aerodrome:	Narita Airport
Estimated off-block time:	17:40
Cruising speed:	M083
Cruising altitude:	FL310

Route:

GIRAF (reporting point) – Y808 (airway) – ALLEN (reporting point) – Y812 (airway) – ABETS (reporting point) – the rest skipped

Destination aerodrome:	San Francisco International Airport
Total estimated elapsed time:	9 h 10 min

At the time of the serious incident, the Captain was sitting in the left seat as the PF (pilot flying; primarily responsible for aircraft control), First Officer A was sitting in the right seat as the PNF (pilot not flying; primarily responsible for duties other than aircraft control) and First Officer B was sitting in the jumpseat as a relief pilot.

The flight history of the Aircraft from when it took off from Narita Airport up to when the serious incident occurred is outlined below, based on the communications between the Aircraft and Air Traffic Control (hereinafter referred to as "ATC") at Narita Airport, the records of the digital flight data recorder (hereinafter referred to as "the DFDR") and the statements of the flight crewmembers.

2.1.1 History of the Flight Based on ATC Communications Records and the DFDR Records

Around 17:58	The Aircraft took off from Runway 16R of Narita Airport.
18:03:43 – 45	At an altitude of about 11,700 ft, the variable stator vanes (hereinafter referred to as the "VSV")*[1] of the Aircraft's right engine began a change in the closed direction. In addition, the following occurred on the right engine: the exhaust gas temperature (EGT) rose; vibrations were generated; the bleed valves*[2] opened; the rotation speed (N1) of the low pressure compressor (hereinafter referred to as the "LPC") and the rotation speed (N2) of the high pressure compressor (hereinafter

*[1] : The "variable stator vanes" regulate the air flow inside the engine, thereby achieving higher compression efficiency and stability.

*[2] : The "bleed valve" is designed to regulate the flow of bleed air from the engine, thereby preventing surging (extreme disturbance of air flow in the engine) and the risk of engine malfunction or stall.

referred to as the “HPC”) both started to drop; and the fuel flow rate dropped to zero.

18:04:07 The Aircraft reported to the Tokyo terminal control facility (hereinafter referred to as “the Departure”) that it was returning to Narita Airport due to engine failure.

18:04:20 The Aircraft declared an emergency to the Departure.

18:04:27 The throttle lever for the Aircraft’s right engine was retarded to the idle position.

18:04:35 The fuel cutoff lever for the Aircraft’s right engine was moved to the cut off position.

18:09:25 The Aircraft reported to the Departure that it had begun jettisoning fuel.

About 18:46 The Aircraft landed on Runway 16R at Narita Airport.

2.1.2 Statements of Flight Crewmembers

(1) Captain

In the preflight check, the Electronic Engine Control (EEC) for the right engine was a deferred repair*3 item, but this would not pose a threat to the flight. Other than that, everything was fine. The pushback started at 17:33, seven minutes earlier than scheduled. The takeoff went smoothly with all engine readings normal. During the climb, there were no problems with the engine readings.

About seven minutes after takeoff, when the Aircraft had climbed to above 11,300 ft, a loud “bang” was heard and then a “whine” came from the right engine. Within about three seconds, N2 of the HPC dropped to nearly zero. The Aircraft’s nose swerved about 10° to the right. Several seconds after the “bang,” the right engine readings were substantially lower than the normal ranges.

The Captain loudly called out, “Engine failure!” The two First Officers performed the Severe Engine Damage Check List. The Captain sent a message to the Departure that the right engine had stalled and that it was necessary to return to Narita after jettisoning fuel. The Captain declared an emergency and transmitted a request to ATC to place emergency vehicles on standby for landing. The Captain explained the situation to the cabin and told them to prepare for an emergency landing.

There was no indication of engine fire. The two First Officers completed the required procedures for the right engine. First Officer A started the Fuel Jettison Check List while First Officer B set up communication with the UA Flight Operation Department in Chicago as well as the United Station Operations at Narita Airport. Subsequently, fuel jettison was started.

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*3 : No aircraft is to take off with inoperable instruments or equipment installed. However, if the inoperable item is listed on the Minimum Equipment List (MEL), the aircraft may take off by treating the inoperable item as a “deferred repair” part, under the operation conditions and limitations specified in the MEL. The repair of the item must be completed by the specified date.

Considering the possibility that the left engine might become inoperative during fuel jettisoning, the Captain decided to land even though the Aircraft slightly exceeded the landing weight, and the Captain stopped the fuel jettisoning when the Aircraft's weight was reduced to 480,000 lb. The allowable gross landing weight at the time was 460,000 lb. The actual weight of the Aircraft at the time of landing was 473,000 lb.

When the runway came into view, the Captain disengaged the autopilot and operated the Aircraft manually. At 18:48, the Aircraft landed at Narita Airport. Just off the runway, there was contact from an airport emergency staff confirming that there was no fire or damage on the Aircraft. Once in the spot, a maintenance engineer came over and asked the Captain how the landing was, and the Captain told him that it was a soft landing.

(2) First Officer A

No abnormalities were found during the pre-flight preparation. The takeoff and climb were normal. When the Aircraft was climbing, at around 11,000 ft, there was a "bang" and the Aircraft yawed slightly. The Captain called out loudly, "Engine failure!" and instructed, "I'll control the Aircraft and handle ATC communication. You two perform the check list." First Officer A performed the Engine Failure Check List together with First Officer B.

(3) First Officer B

Seven minutes after the takeoff, when the Aircraft was climbing through around 11,000 ft, the right engine failed and stalled. There was a creaking noise for 3 to 4 seconds, followed by a sudden "bang," and the engine failed. The Captain continued to control the Aircraft while First Officer B carried out emergency operations together with First Officer A.

The serious incident occurred around 18:04 on July 28, 2010, at an altitude of about 11,700 ft, about 46 km east-southeast of Narita Airport.
(See Figure 1 – Estimated Flight Route; Figure 2 – DFDR Records; Figure 3 – Three Angle View of Boeing 777-200; and Photo 1 – Serious Incident Aircraft.)

2.2 Injuries to Persons

No one was injured.

2.3 Damage to the Aircraft

The inside of the right engine was destroyed.

The HPC was unable to rotate. An inspection of the inside of the HPC using a borescope inserted through the inspection holes, revealed that dust-like material was adhering to the inside, and the blades and vanes were broken. Some of the inspection holes were clogged with the adhering material, preventing the entry of the borescope. The entire surface of the diffuser in front of the combustion chamber and that of the inside of the high-pressure turbine were covered with dust-like material.

2.4 Other Damage

None

2.5 Personnel Information

(1) Captain: Male, Age 54

Airline Transport Pilot Certificate	February 20, 2008
Type rating for Boeing 777-200	December 15, 2002
Class 1 Aviation Medical Certificate	
Validity	February 10, 2011
Total flight time	22,400 h 00 min
Flight time in the last 30 days	30 h 00 min
Total flight time on the type of aircraft	5,300 h 00 min
Flight time in the last 30 days	30 h 00 min

(2) First Officer A: Male, Age 52

Airline Transport Pilot Certificate	March 8, 2008
Type rating for Boeing 777-200	September 25, 2002
Class 1 Aviation Medical Certificate	
Validity	November 21, 2011
Total flight time	10,109 h 00 min
Flight time in the last 30 days	24 h 34 min
Total flight time on the type of aircraft	4,459 h 00 min
Flight time in the last 30 days	24 h 34 min

(3) First Officer B: Male, Age 49

Airline Transport Pilot Certificate	January 20, 2010
Type rating for Boeing 777-200	January 20, 2010
Class 1 Aviation Medical Certificate	
Validity	July 22, 2011
Total flight time	8,300 h 00 min
Flight time in the last 30 days	78 h 37 min
Total flight time on the type of aircraft	490 h 00 min
Flight time in the last 30 days	78 h 37 min

2.6 Aircraft Information

2.6.1 Aircraft

Type	Boeing 777-200
Serial number	30551
Date of manufacture	January 23, 1997
Certificate of airworthiness	
Date of issue	January 22, 1991

Validity

Period while maintenance and modification are done per FAR

Category of airworthiness	Airplane, Transport T
Total flight time	39,773 h 41 min
Flight time since last periodical check	1,323 h 39 min
(C04 check on May 13, 2010)	

2.6.2 Engines

(1) Left engine

Type	Pratt & Whitney PW4090-3
Serial number	222048
Date of manufacture	October 14, 1997
Total time in service	51,442 h 00 min
Flight time since last periodical check	1,323 h 39 min
(C04 check on May 13, 2010)	

(2) Right engine

Type	Pratt & Whitney PW4090-3
Serial number	222178
Date of manufacture	November 15, 2001
Total time in service	31,030 h 43 min
Total cycles in service	3816
Flight time since last periodical check	1,323 h 39 min
(C04 check on May 13, 2010)	

2.6.3 Weight and Balance

When the serious incident occurred, the Aircraft's weight is estimated to have been 563,054 lb and its center of gravity is estimated to have been 26.7% mean aerodynamic chord (MAC), both of which are estimated to have been within the allowable range (maximum takeoff weight of 568,960 lb, and 15 to 44% MAC corresponding to the weight of the Aircraft at the time of the serious incident). At the time of landing, the Aircraft's weight is estimated to have been 471,754 lb and its center of gravity is estimated to have been 24.8% MAC. It is, therefore, considered highly probable that the actual landing weight exceeded the allowable range (maximum landing weight of 460,000 lb and 14 to 44% MAC corresponding to the weight at the time of the serious incident) by 11,754 lb.

2.6.4 Fuel and Lubricating Oil

The fuel used in the Aircraft was aviation fuel Jet A-1. The lubricating oil was BP2197.

2.7 Meteorological Information

The aerodrome routine meteorological reports (METAR) for Narita Airport around the time of the serious incident were as follows:

18:00 Wind direction 180°, Wind velocity 10 kt, Visibility 30 km

	Cloud: Amount FEW*[4],	Type Cumulus,	Cloud base 3,500 ft
	Amount BKN*[5],	Type Unknown,	Cloud ceiling Unknown
	Temperature 29°C,	Dew point 21°C	
	Altimeter setting (QNH) ... 29.83 inHg		
18:30	Wind direction 180°,	Wind velocity 10 kt,	Visibility 30 km
	Cloud: Amount FEW,	Type Cumulus,	Cloud base 3,000 ft
	Amount BKN,	Type Unknown,	Cloud ceiling Unknown
	Temperature 28°C,	Dew point 21°C	
	Altimeter setting (QNH) 29.84 inHg		

2.8 Information on the DFDR and Cockpit Voice Recorder

The Aircraft was equipped with a DFDR (Part Number 980-4700-042) and a cockpit voice recorder (CVR) (Part Number 980-6020-001), both made by AlliedSignal (now Honeywell) of the United States of America. The DFDR retained data relevant to the serious incident. The time was determined by correlating the DFDR-recorded VHF transmission keying signals with the NTT time signal recorded on the ATC communication records.

The CVR, capable of recording a period of about 30 minutes, did not retain data for the time at and around the serious incident because the data was overwritten as the Aircraft continued operation after the serious incident.

2.9 Information on the Engines

The Pratt & Whitney PW4090-3 is a dual-axial turbofan engine, consisting of the following: a seven-stage LPC, the first stage of which are fan blades; an eleven-stage HPC; a diffuser; a combustion chamber; a two-stage HPT; a seven-stage LPT; exhaust piping,; and a main accessory drive gearbox, which include, a fuel control, a fuel pump, a hydraulic pump, a lubrication pump, generators, an alternator. Additional engine mounted accessories and components include EEC, VSV actuator, a compressor starter and stability valves and the others.

The VSV changes its angle as follows: An electric control signal is sent from the EEC to the VSV actuator which then uses servo fuel pressure to actuate the VSV actuator. Then, the movement of the actuator is transmitted via the synchronizing ring (hereinafter referred to as "the Ring") and the lever arm (hereinafter referred to as "the Arm") to the VSV. The Arm pivots around a lever arm pin (Part Number 54H727, hereinafter referred to as "the Pin"), which is welded to the Ring.
(See Figure 4 – Sectional View of the Engine; Figure 5 – HPC; and Figure 6 – Structure of the Synchronizing Ring.)

2.10 Details of the Damage

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*[4] : "FEW" (few) corresponds to cloud amounts of 1/8 – 2/8.
*[5] : "BKN" (broken) corresponds to cloud amounts of 5/8 – 7/8.

By request from JTSB to the National Transportation Safety Board (NTSB), teardown inspection was conducted on the right engine at the UA maintenance factory in the United States of America under the presence of NTSB representatives during the period from August 23 to 27, 2010. The inspection report identified the major damage to the engine as follows:

(1) The trailing edges of all 4th stage LPC rotor blades were severely damaged. Almost all of the trailing edges of the 4th stage vanes had cuts.

(2) All of the VSVs and HPC rotor blades were damaged.

(3) The #73 Arm (viewed from the rear of the engine, Arms are numbered clockwise, with the right outermost Arm as #39), which was connected to the inlet guide vane (IGV), located foremost among the VSVs of the HPC, was deformed into the shape of a "Z." Contact marks were evident on the Ring, which appeared to have been caused by interference with the Arm. The Pin connecting the #73 Arm and the Ring was missing.

The Pins are permanently connected to the Ring with a flared head at installation and then secured with two small welds. However, the two welded points were broken. The fractured surfaces of the welds and holes were corroded.

(4) Of the 40 5th stage HPC rotor blades, only three remained on their mounts while the other blades had broken off at their mounts.

(5) About half of the 5th stage VSVs of the HPC had broken off at their mounts. All of the remaining vanes were bent in the direction of rotation.

(6) All of the 6th stage HPC rotor blades were broken. About half of the blades were broken on the outer sides and were bent in the reverse direction of rotation. Ten blades were missing, including their bottom portions.

(7) All of the 6th stage and 7th stage VSVs of the HPC were in place, although they had tears and bruises on their leading and trailing edges.

(8) All of the 7th stage HPC rotor blades were in place, although about half were severely broken. All of the blades were bent in the reverse direction of rotation.

The comments of the NTSB based on the results of the teardown inspection are as follows.

It is considered probable that the serious incident occurred because one of the IGVs of the HPC became uncontrollable and moved to the closed position. It is considered highly probable that the cause of the above was the broken Pin for the IGV Arm of the HPC. In the closed position, this single vane obstructed the air flow in the HPC. Downstream from the IGV of the HPC were the 5th stage rotor blades. These blades were subjected to pulsating air flow caused by the closed vane, instead of ordinary uniform air flow from the IGV. The HPC rotates at about 10,000 rpm. Therefore, the 5th stage HPC rotor blades were subjected to pulsation of 10,000 times per minute. This could be the cause of the vibration leading to fatigue fracture. To find the evidence of the fatigue fracture, it is recommended that the 5th stage HPC rotor blades be thoroughly analyzed.
(See Photo 2 – HPC; Photo 3 – Damage to the Inside of the HPC; and Photo 4 – Condition of the Synchronizing Ring (top) and Cracked Pin Weld (bottom).)

2.11 Tests and Research for Fact-Finding

Based on the results of the teardown inspection, numerous broken pieces including those of the IGV and 5th stage rotor blades were thoroughly analyzed at a research facility of the engine manufacturer with the cooperation of the NTSB. The analysis report is outlined below.

(1) Condition of damaged areas

The lower IGVs Ring (Part Number 55H965-01, Serial Number 33611) was visually inspected. The lower Ring had the #39 to #74 Pins and the related Arms. The holes for the #63, #67 and #70 Pins were not coated with anticorrosive (aluminum enamel) and were discolored from heat. This indicated that these Pins had been repaired by welding. Each of the Pins had been tack-welded in two locations between the outer surface of the Ring and the outer end of the Pin, in the circumferential direction, to prevent the Pin from rotating.

The upper IGV Ring (Part Number 55H954-01, Serial Number 33611) was also visually inspected. The upper Ring had the #1 to #38 Pins (viewed from the rear of the engine, pins are numbered clockwise, with the left outermost Pin as #1) and the related Arms. All of the pin holes were coated with anticorrosive. Each Pin had two tack welds to prevent the rotation of the Pin in the axial direction of the Ring.

(2) Findings

① Examination of the IGV Rings

Microscopic examination of the lower IGV Ring revealed the following: Nine (#46, #49, #51, #55, #62, #63, #65, #67 and #74) of the 36 Pins could be rotated in their pin holes because the fractured welds. The remaining Pins, except #45, #60 and #74, more or less had various cracks in the welds. The pin hole of the missing #73 Pin had become slightly oval.

Microscopic examination of the upper IGV ring revealed that the welded portions at all of the 38 Pins were free of any damage.

The flare diameters of the Pins were measured at the outer surfaces of the upper and lower IGV Ring assemblies. Of the 36 Pins on the lower IGV Ring, 17 Pins were smaller than the specification (0.170 in). Of the 38 Pins on the upper IGV Ring, 34 were smaller than the specification (0.170 in). All of the Pins, except #63, #67 and #70, were coated with aluminum enamel anticorrosive. The lower IGV Ring was cut at the locations of #70, #71 and #74 Pins in order to remove the Pins with damaged welded portions. The Pins were worn to various degrees in the areas that had been in contact with the Ring and Arm, and the load bearing surfaces of the Pins were worn. The wear was generally smooth and had no directional inclination or other characteristics, which is typically seen on wear by high-frequency resonance with small amplitude. The diameters of the Pins in the areas with no wear conformed to the specification. The #39 to #60 Pins were removed from the lower IGV Ring to evaluate the diameters of the pin holes. The diameter of the hole for the #49 Pin, which could be rotated in its place before removal, was 0.172 in, the largest of all the measurements taken. The #46, #54 and #56 pin hole diameters were 0.162 in. The #42 pin hole diameter was 0.163 in. The specified maximum value is 0.161 in.

The openings of the cracks at the welded portion were inspected through a microscope. The areas generally showed typical characteristics of internal dendritic fracture (hereinafter referred to as "solidification cracking"*6). The fatigue fracture under the heat of a running engine seemed to have been caused not by overstress, but by solidification cracking.

In several spots of the cracked welds, there were cavities caused by shrinkage porosity near the boundaries with the adjoining metal.

Hardness tests were conducted on the axial and top portions of the #70, #71 and #74 Pins, which all met the specification.

Metallographic analysis of the longitudinal sections of the Pins showed that oxidized material had deposited on the worn surfaces that seem to have formed through friction.

Metallographic analysis was made on cross sections across the pin holes and welded portions of the #68, #69, #72 and #73 Pins. The welding rod used met the specifications. The welding height and length met the specifications. Aside from the cavities caused by shrinkage, the microstructure of the welded portions generally showed no abnormalities. The cracks, largely from solidification, had started from the ends of the weld.

The microstructure of the Rings showed typical characteristics of appropriately manufactured stainless steel. The microstructure of the Pins showed typical characteristics of appropriately manufactured nickel steel.

② Examination of the IGV

The IGVs were so extensively broken that it could not be determined where the broken vanes were originally mounted. Therefore, the vane that was originally connected to the #73 Arm, for which the Pin was missing, was not identified.

③ Examination of the 5th stage HPC

All of the 5th stage rotor blades were broken. The mounts for several of these blades were also missing. Two mounts clearly showed the marks of high-frequency fatigue. Several 5th stage HPC disc lugs were broken off.

④ Examination of the 5th stage HPC Synchronizing Rings

The runner at the 2 o'clock position viewed from the rear of the engine was broken. Other than that, there was no damage to the upper and lower Synchronizing Rings and the Pins. About half of the VSVs were broken off. The

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*6 : "Solidification cracking" shows the characteristics of grain boundary cracking. This is a type of welding defect that occurs when welded metal cannot withstand the contraction strain in the solidification shrinkage process and eventually separates, typically at dendritic boundaries and their crossings.

remaining VSVs were severely bent in the direction of rotation. The rotor blades and vanes downstream from the HPC were severely broken.

(3) Summary

The analysis clearly shows that the lower IGV Ring had been repaired in the past, and the Pins for the Arms had been replaced. Before conducting welding to prevent rotation, it must be ensured that there is no clearance between the Pin and the pin hole. On the #73 Arm position, it appears that cracks had developed from a shrinkage porosity on the welds connecting the Pin and the Ring, eventually allowing the Pin to rotate. The Pin rotated in the pin hole every time the Ring moved, and the Pin and the pin hole underwent gradual wear. The wear progressed to the point of Pin escape, allowing the Arm to be released from the Ring. Eventually, as the Arm did not move smoothly with the Ring, the end of the Arm was bent by the Ring and became stuck. The #73 IGV became stuck at an angle about 90° relative to the air flow. Subsequently, the 5th stage HPC rotor broke due to high-frequency fatigue, resulting in major damage to the engine.

(See Photo 2 – HPC; Photo 3 – Damage to the Inside of the HPC; and Photo 4 – Condition of the Synchronizing Ring.)

2.12 Additional Information

2.12.1 Emergency Operations

In the “Emergency Procedure” section of the UA flight manual, the procedure to be followed by the pilots in the event of engine failure is as follows.

Severe Engine Damage Check List (Section 15.30.7)

Condition: Engine has severe damage, vibration or has separated.

*QRC*7 ACTION:*

- *Autothrottle arm switch* ………………… *Off*
- *Throttle* ………………… *Idle*
- *Fuel control switch* ………………… *Confirm, cutoff*
- *Engine fire handle* ………………… *Confirm, pull*
- *QRC Driftdown*8 procedure* ………………… *Consider*

2.12.2 EEC Error

Examination of the EEC fault memory revealed that the message “Oil pressure transmitter signal out of range” was displayed for Channel B of the EEC installed on the right engine during Flight 882 (the flight prior to Flight 852 during which the serious incident occurred). Regarding this item, operation of the Aircraft is allowed by applying the MEL

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*7 : “QRC” is an acronym for Quick Reference Checklist, which lists in a simple format a set of actions required to be taken in an emergency.

*8 : “Driftdown” means descending to an altitude at which stable flight is possible in the event of engine failure or rapid depressurization.

(Minimum Equipment List) of UA, on the condition that repair will be completed within 20 days. During Flight 852, this message was not displayed.

2.12.3 Engine Maintenance History

The engine was manufactured on November 15, 2001. Recent major maintenance carried out on the engine is as follows:

・April 24 – June 15, 2009	Shop maintenance at the UA maintenance factory; Borescope inspection of the inside of the HPC
・June 26, 2009	The engine was installed on the Aircraft as its right engine.
・May 13, 2010	Periodic C04 check; Borescope inspection of the inside of the HPC
・July 11 – 21, 2010	On-wing maintenance (the engine is serviced without removing it from the Aircraft); Borescope inspection of the inside of the HPC

As to whether or not the IGV Ring was repaired in the past, UA stated that they had no record regarding the repair of the Ring and they could not trace the Ring's repair history.

The manufacturer of the engine stated that they did not fully grasp the scope of the flight operation made with the Ring and the repair on the Ring. The engine manufacturer also stated that repair on the Ring was not performed at the repair facilities designated by the engine manufacturer, nor was it conducted by observing the procedure specified by the engine manufacturer.

2.12.4 Inspection of the Synchronizing Rings

Service Bulletin No. PW4G-112-72-206 (hereinafter referred to as "the SB") dated September 8, 1999, issued by the engine manufacturer, describes how to find cracks and deterioration of welds on the Rings and Pins. The SB recommended carrying out inspection and other maintenance works on Pins and other parts of Pratt & Whitney PW4090-3 and other types of engines. In short, it recommends the following: Carry out the first inspection when the Ring has reached 1,500 cycles of operation, and thereinafter inspect once every 800 cycles. However, if three or more weld cracks, a loose Pin, or other problem is found, carry out the inspection once every 150 cycles and send the inspection results to the engine manufacturer. Subsequent to the engineering analysis of the root cause, test on the vanes and review of field inspection reports, the engine manufacturer concluded that the Pins used on the Pratt & Whitney PW4090-3 engine were not prone to deterioration, because the Ring was changed from a fabricated sheet steel construction to a single piece forging. The forged Ring has a different vibratory response and therefore the inspection was not necessary. On January 13, 2004, the engine manufacturer revised the SB accordingly and abolished the relevant inspections.

3. ANALYSIS

3.1 Crew Qualifications

The Captain, First Officer A and First Officer B held valid airman competence certificates and valid aviation medical certificates.

3.2 Airworthiness Certificate

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

3.3 Meteorological Conditions

It is considered highly probable that the meteorological conditions at the time of the serious incident had no bearing on the occurrence of the serious incident.

3.4 Handling of the Serious Incident by the Captain

When the right engine failed, the Captain, as PF, continued to control the Aircraft while instructing the two First Officers to perform the Severe Engine Damage Check List, and later he safely landed the Aircraft under excessive weight conditions. From the above, it is considered highly probable that the Captain appropriately performed his duties.

3.5 Progress of Events Leading to the Major Engine Damage

Based on the results of analysis described in 2.11, it is considered probable that the engine failed in the following sequence.

(1) Given that the welded points of many of the Pins on the lower IGV Ring in the right engine were broken and the Pins could rotate in their pin holes, and that Pins near the #73 Pin were worn and their pin holes enlarged as described in 2.11 (3), it is considered highly probable that as the #73 Pin escaped the Ring while the Ring was moving, the #73 Arm was released while the Aircraft was climbing after takeoff. As the #73 Arm was released from the Ring and therefore was able to move freely, the #73 vane connected to the #73 Arm became uncontrollable. The Arm then interfered with the lower IGV Ring and was deformed into the shape of a "Z". As a result, the vane settled in the closed position. With the vane closed to locally obstruct the air flow in the HPC, the air flow in the engine began pulsating.

(2) The 5^{th} stage HPC rotor blades just downstream from the IGV of the HPC were subjected to pulsating air flow caused by the closed vane, instead of a uniform air flow. As a result, the rotor blades broke due to high-frequency fatigue as described in 2.11 (2) ③. Subsequently, the 5^{th} stage VSVs and the HPC rotor blades and VSVs of later stages, located further downstream, broke in rapid succession.

(3) The DFDR records show that the bleed valves for the right engine opened at 18:03:44. It is considered probable that just then surging occurred in the HPC and the IGVs, and the trailing edges of the 4^{th} stage LPC rotor blades just upstream from the IGVs broke as well.

(4) It is considered highly probable that the succession of breakages described above led to the severe engine damage.

(5) As to the fractured welds for the #73 Pin, the pivot for the #73 Arm, it is considered possible that the Pin flare and the welds had not been made in an appropriate manner given the following: in several spots of the cracked welds, there were cavities caused by shrinkage near the boundaries with the adjoining metal; in several locations, and examination of the cracked surfaces of the welds revealed marks of solidification cracking, as described in 2.11 (2) ①.

3.6 Repair on the IGV Synchronizing Ring

As described in 2.12.3, the right engine was manufactured on November 15, 2001. The recent major maintenance conducted on the engine by UA was the shop maintenance carried out at the UA maintenance factory during April 24 – June 15, 2009. The engine was installed on the Aircraft as its right engine on June 26, 2009. Periodic C04 check was carried out on May 13, 2010. On-wing maintenance was carried out during July 11 – 21, 2010.

As described in 2.11 (1), the pin holes for the #63, #67 and #70 Pins were not coated with anticorrosive (aluminum enamel) and were discolored from heat. This indicates that the welded portions of these Pins had been repaired. Regarding this repair, as described in 2.12.3, UA stated that they did not have any repair records on the Ring. In addition, the engine manufacturer stated that they did not fully grasp the scope of the flight operation made with the Ring and the repair on the Ring. The engine manufacturer also stated that repair on the Ring was not performed at the repair facilities designated by the engine manufacturer, nor was it conducted by observing the procedure specified by the engine manufacturer. As described above, because of the incomplete history of engine operation and Ring's repair, it could not be ascertained where and how the repair in question was conducted.

3.7 Recurrence Prevention Measures

As described in 3.5, it is considered probable that the serious incident occurred as a result of a lever arm coming off from the IGV ring, contributed by the fracture of the welded points on a Pin (Part Number 54H727), the pivot of the Arm. As described in 3.6, it is considered possible that the pin flare and welded points were not performed in an appropriate manner during repair of the Ring. Therefore, any operator of an aircraft or engine must need to seek the system building to ensure repairing according to the procedures specified by the engine manufacturer.

4. PROBABLE CAUSE

It is considered highly probable that a lever arm connected to a synchronizing ring for an inlet guide vanes in the right engine came off when the Aircraft was climbing after takeoff, causing pulsation of the air flow in the engine, which then severely damaged the internal components of the engine, resulting in this serious incident.

It is considered possible that fracture of the welded points between the pin (Part Number 54H727), which is the pivot for the lever arm, and the synchronizing ring for the inlet guide vanes contributed to the release of the lever arm.

Regarding the fracture of the welded points, it is considered possible that the Pin flare and welding was not performed in an appropriate manner when repairing the synchronizing rings for the inlet guide vanes.

Figure 1 Estimated Flight Route

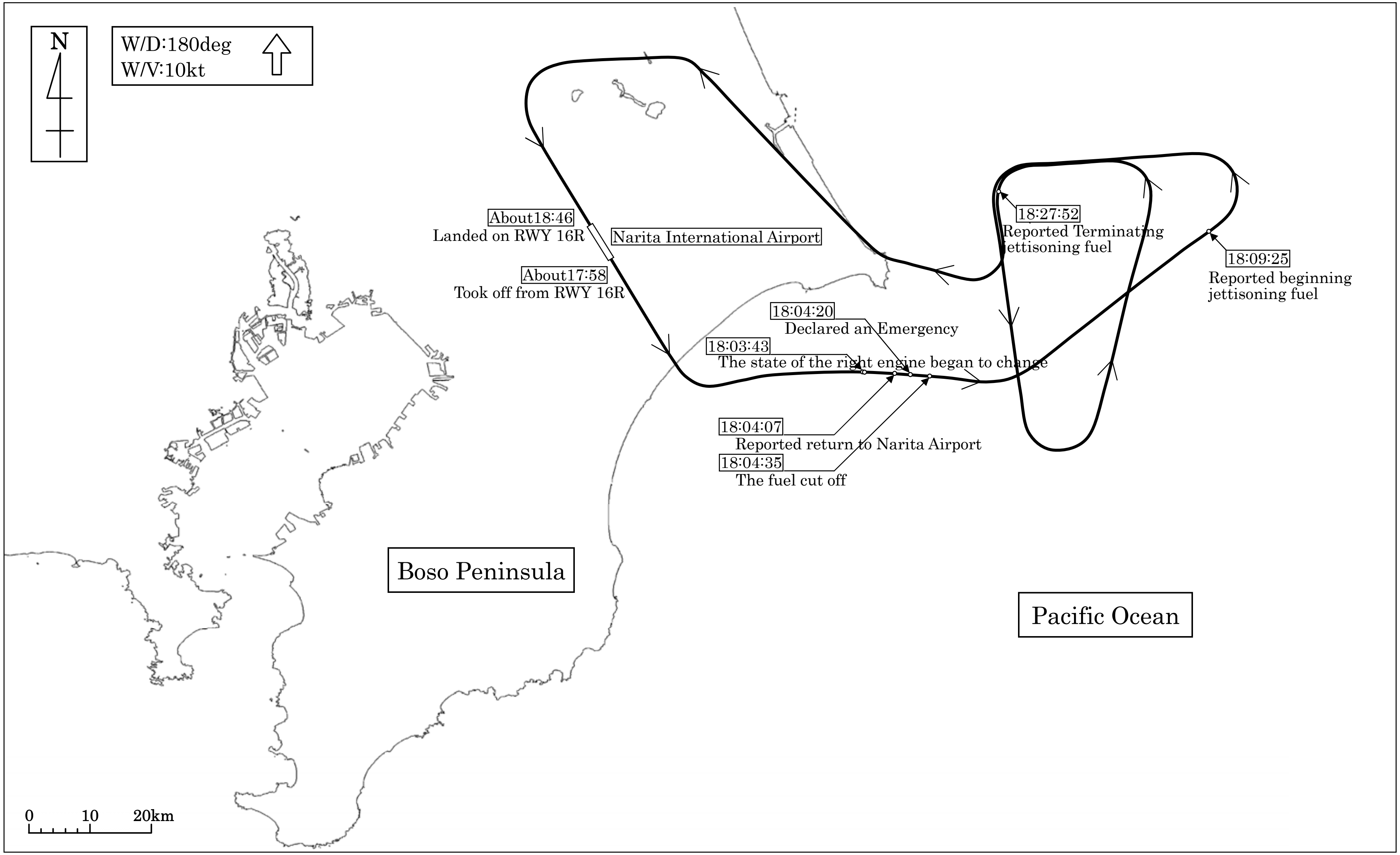


Figure 2　DFDR Records

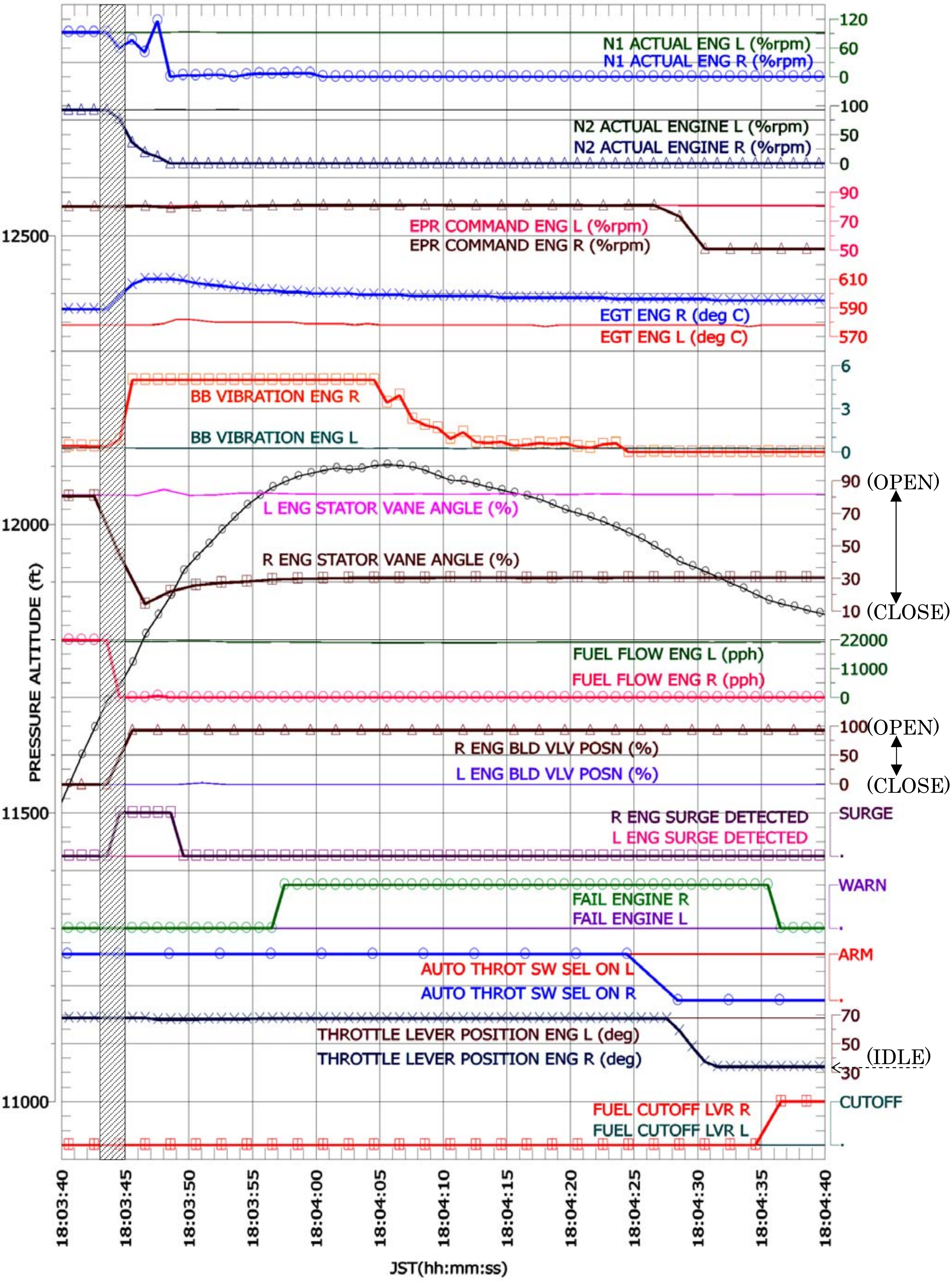


Figure 3　Three Angle View of Boeing 777-200

Unit:m

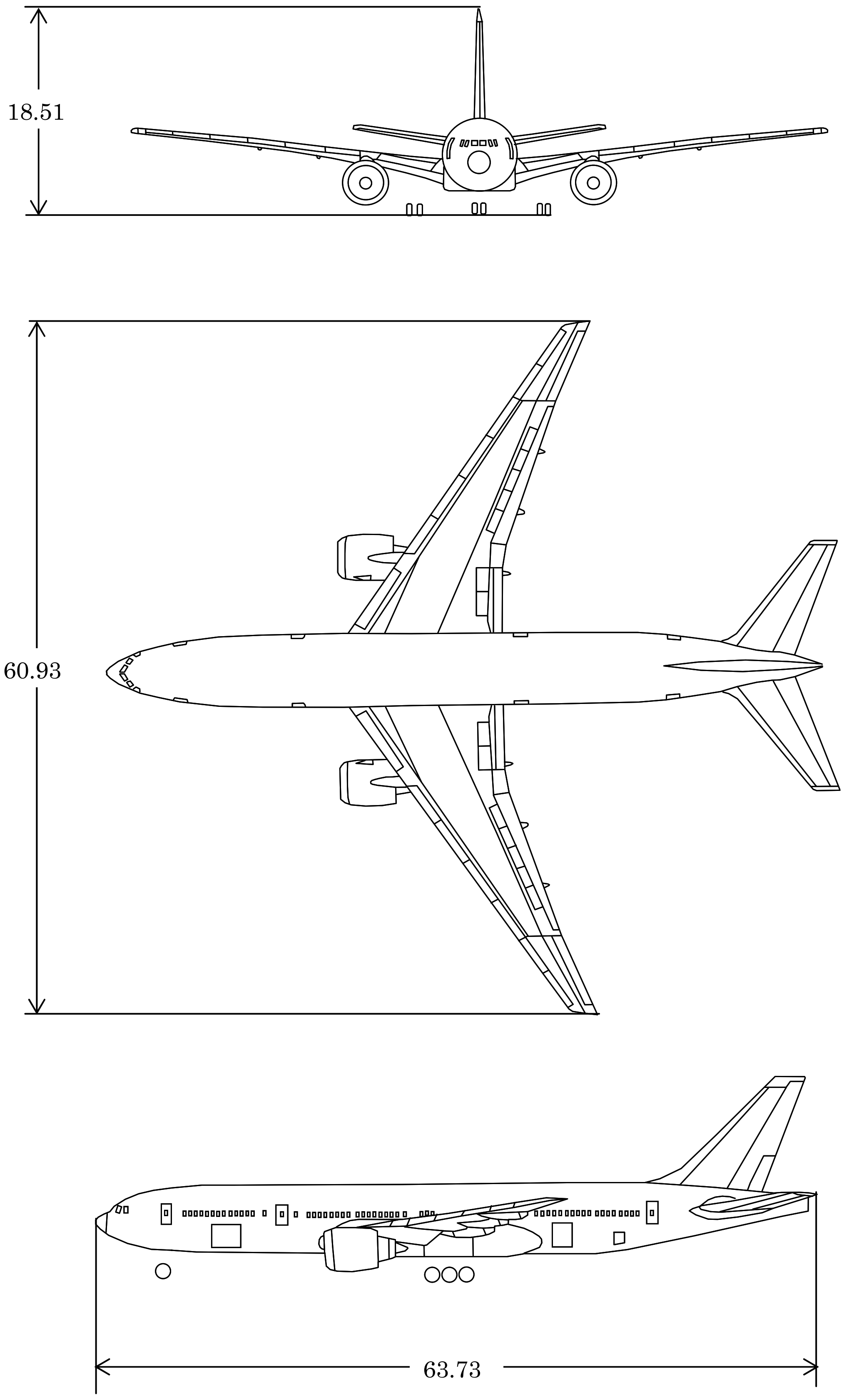


Figure 4 Sectional View of the Engine

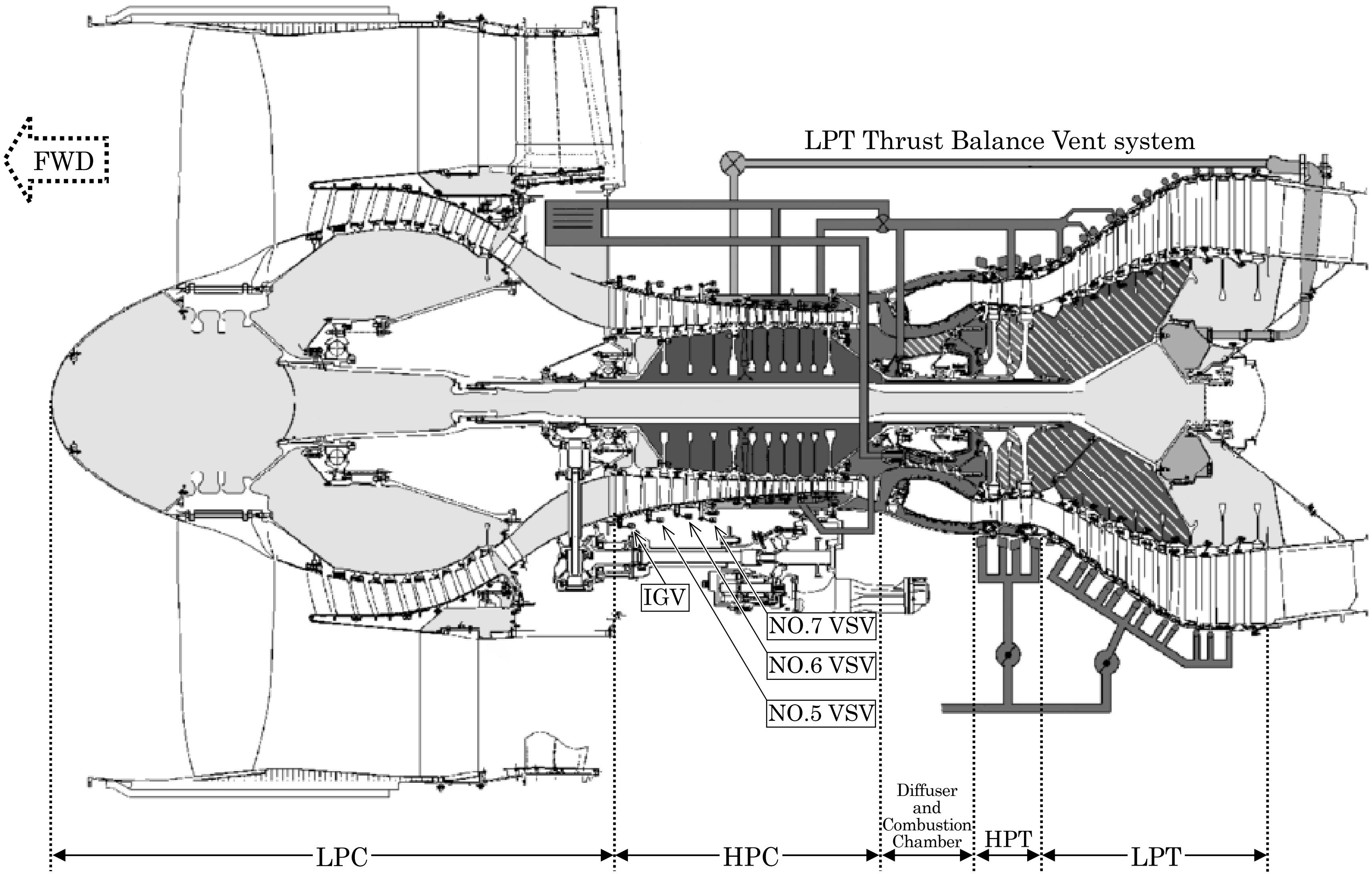


Figure 5　HPC

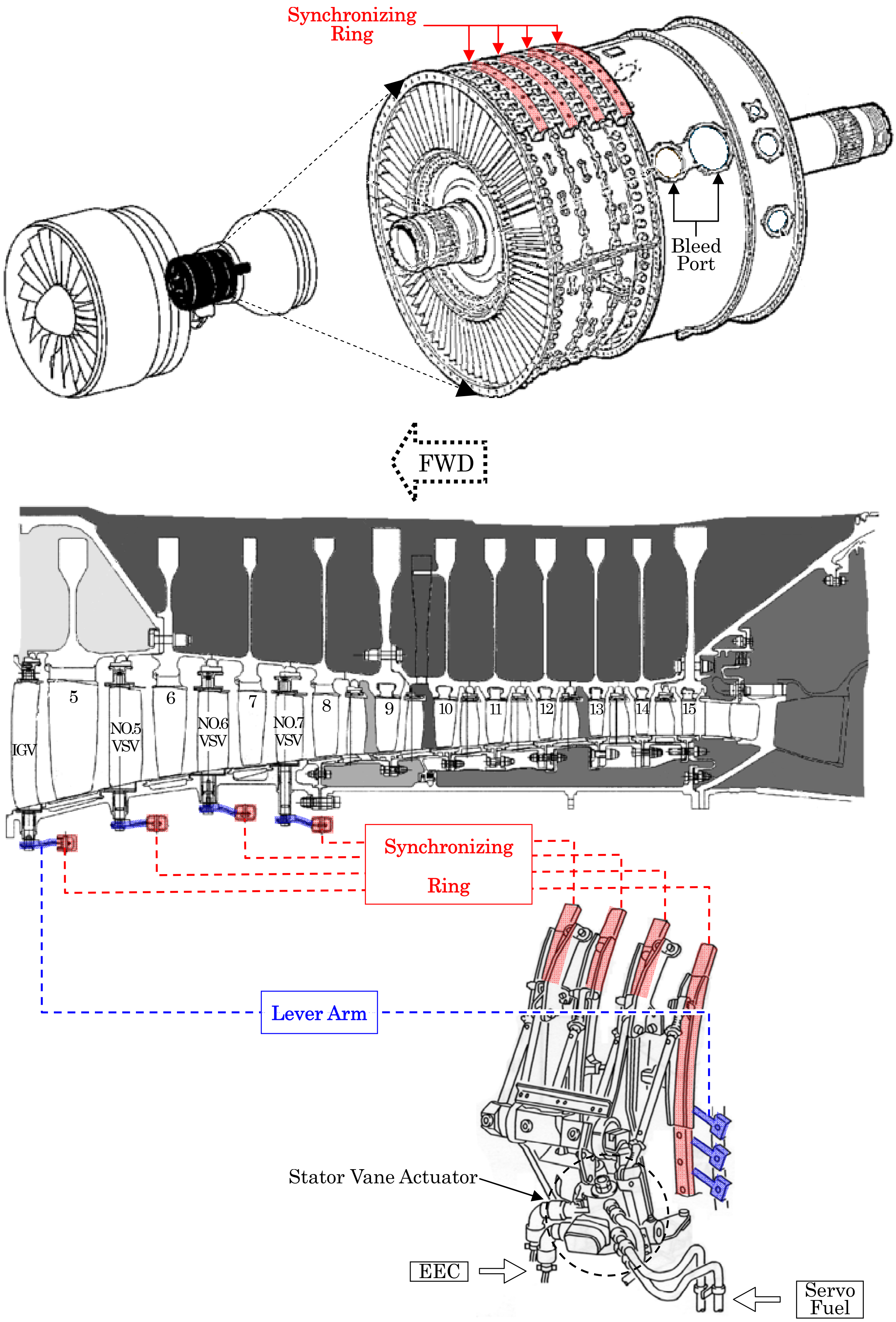

Synchronizing
Ring
Bleed
Port
FWD
5
6
7
8
9
10
11
12
13
14
15
IGV
NO.5
VSV
NO.6
VSV
NO.7
VSV
Synchronizing
Ring
Lever Arm
Stator Vane Actuator
EEC
Servo
Fuel

Figure 6　Structure of the Synchronizing Ring

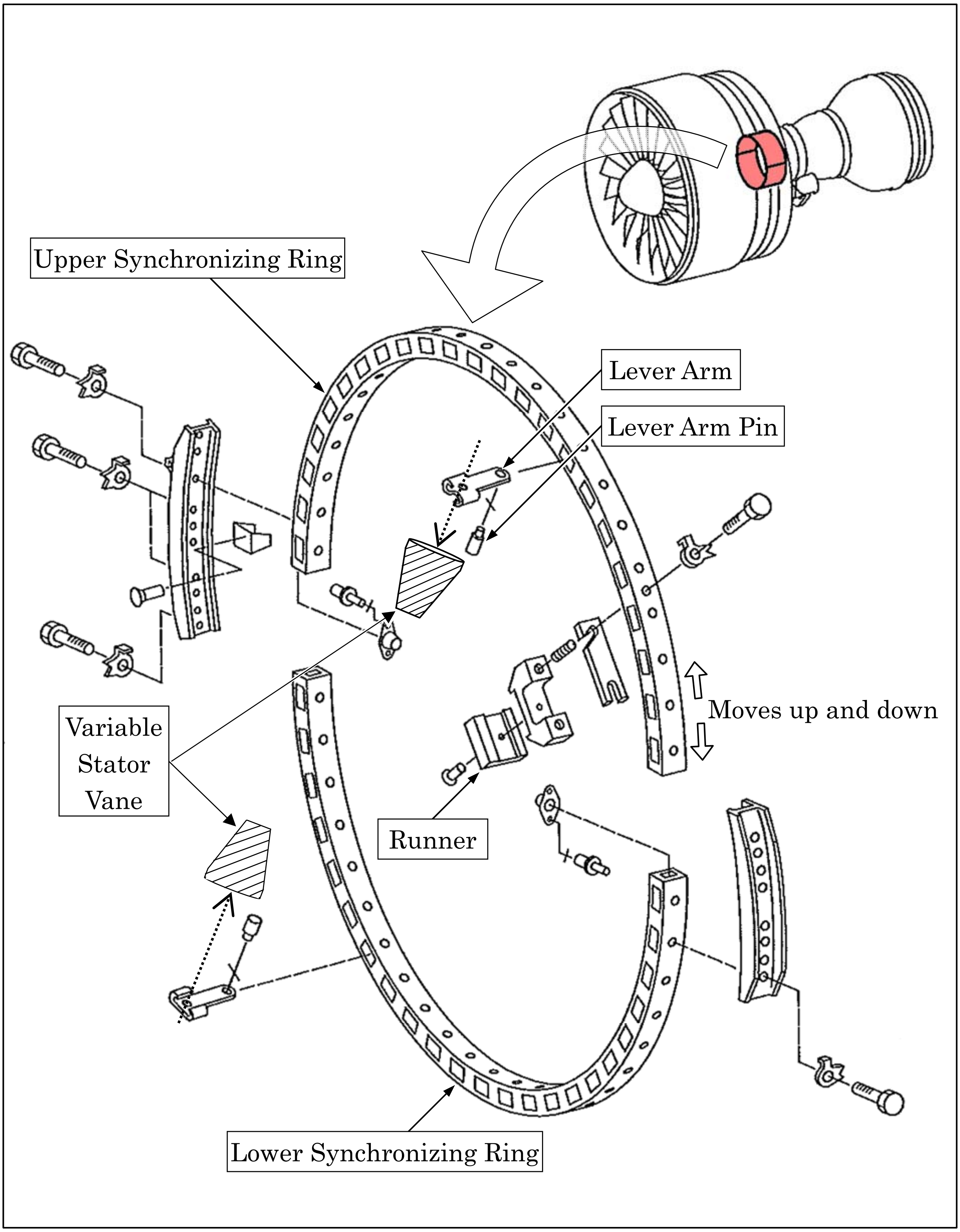


Photo 1　Serious Incident Aircraft

Photo 2　HPC

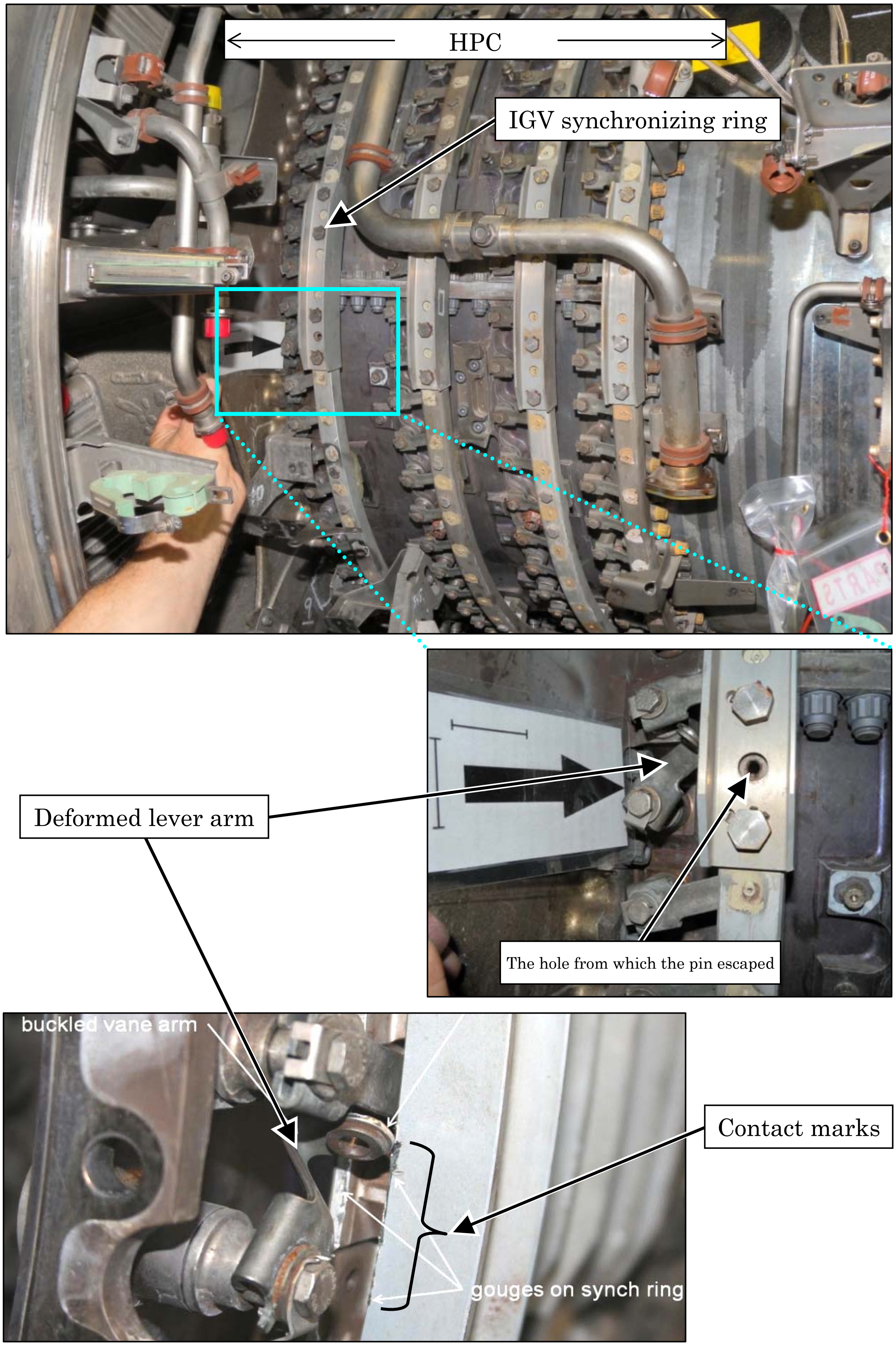

HPC
IGV synchronizing ring
Deformed lever arm
The hole from which the pin escaped
buckled vane arm
Contact marks
gouges on synch ring

Photo 3　Damage to the Inside of the HPC

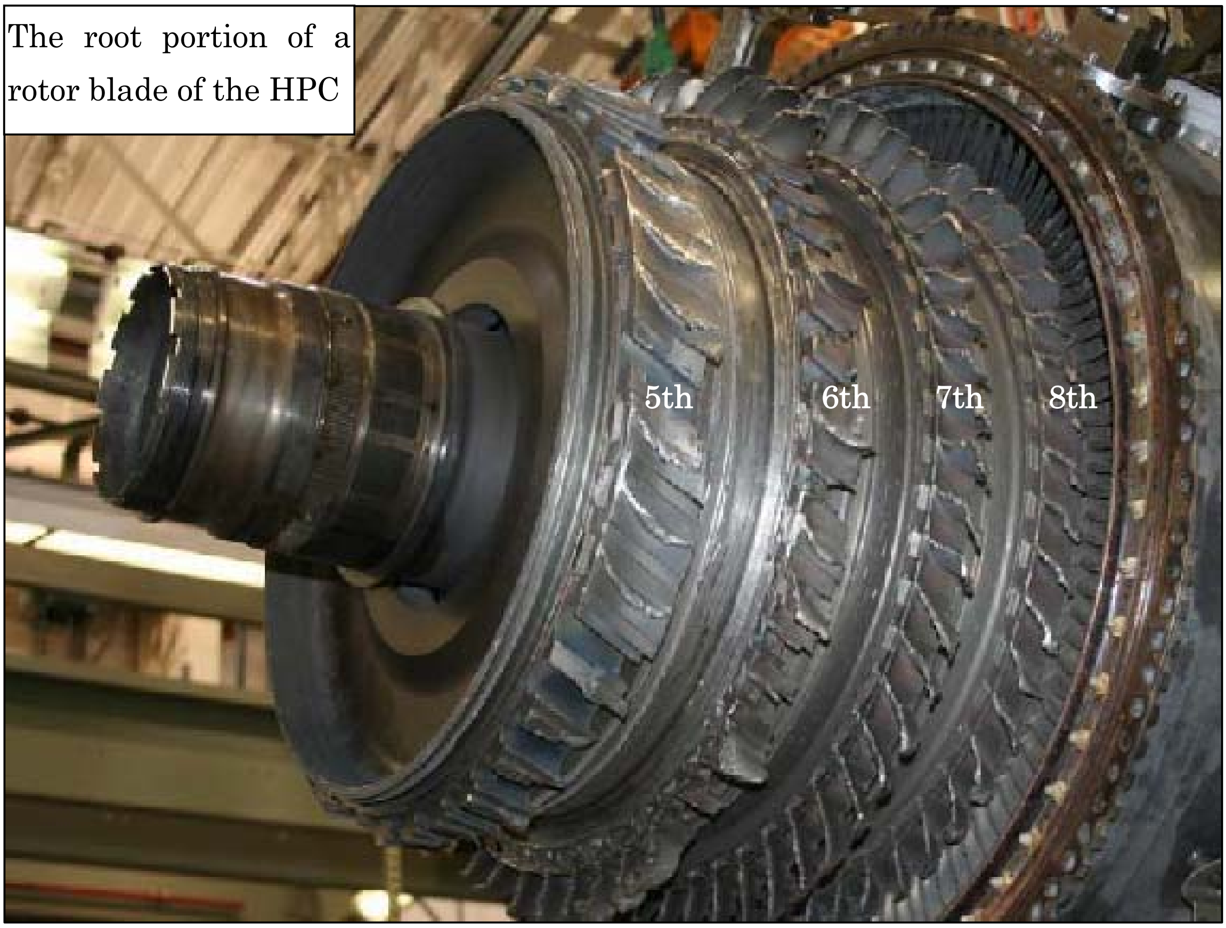
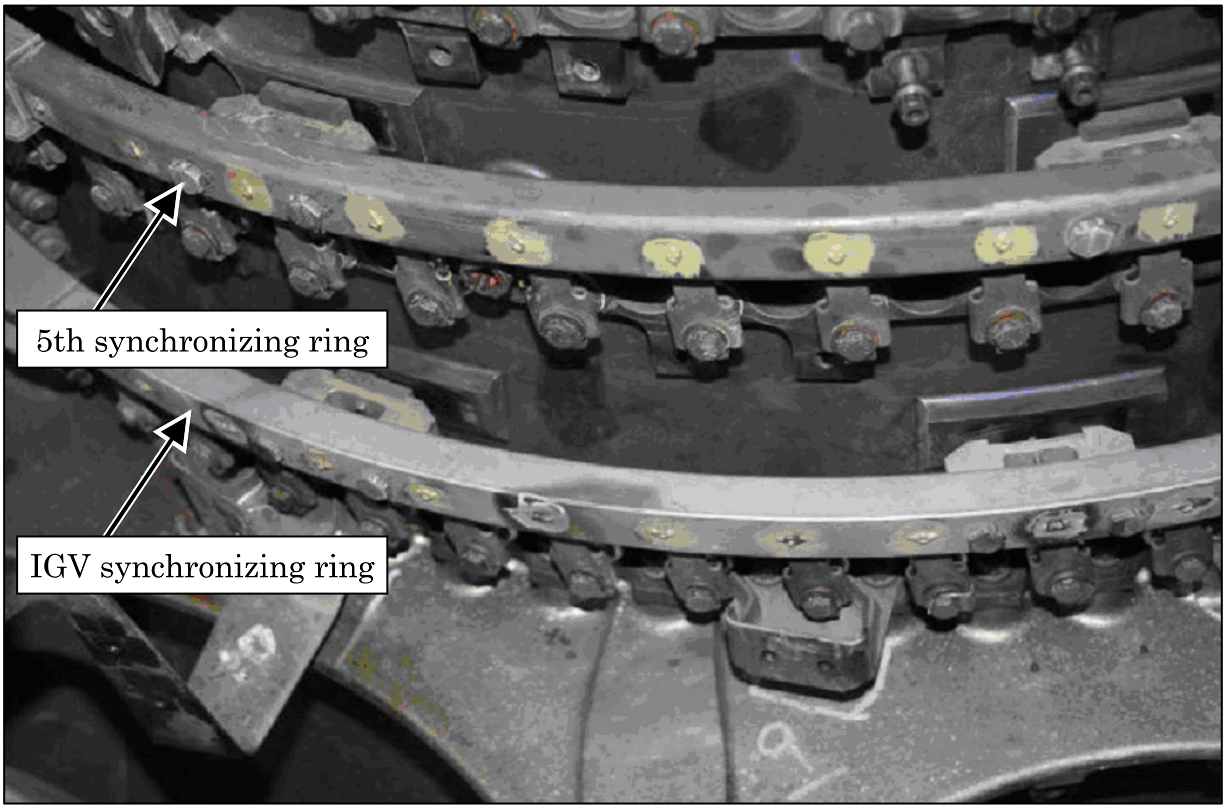
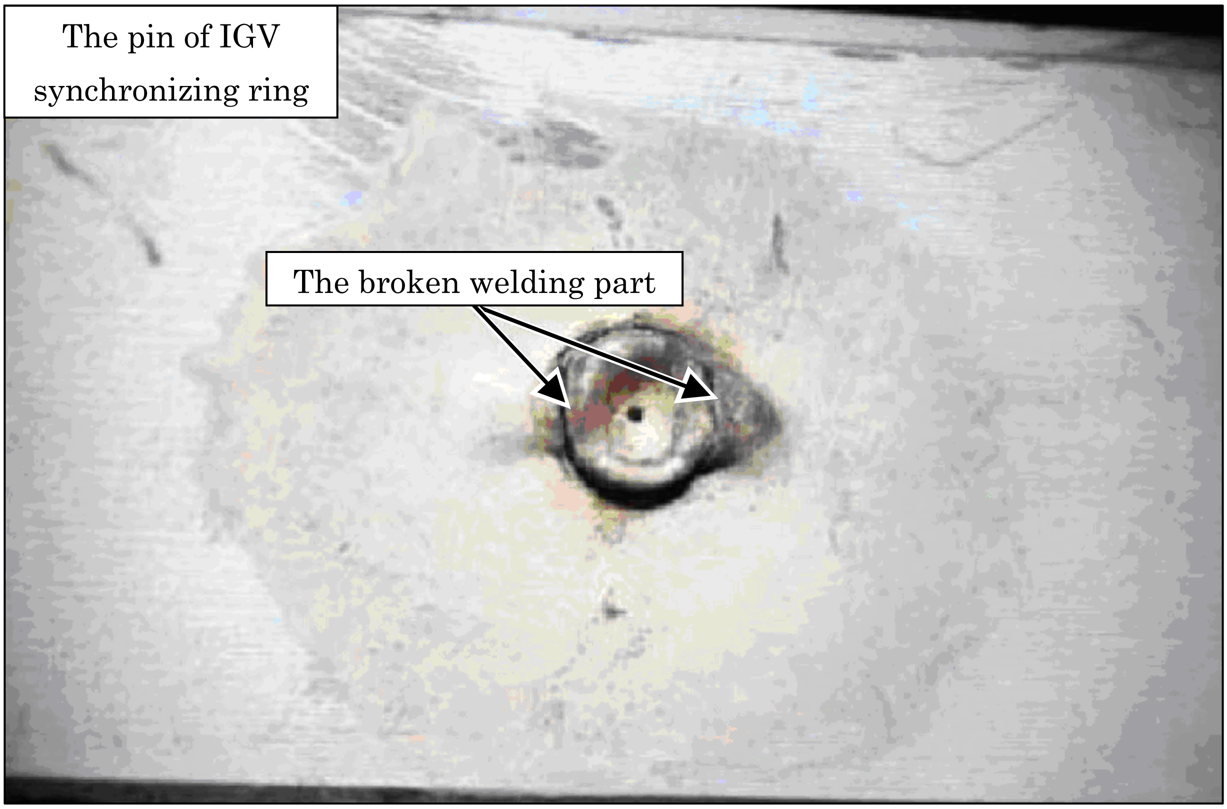


Photo 4 (Upper) Conditions of the synchronizing ring
(Lower) Cracked pin weld





Abbreviation

ＢＫＮ	Broken
ＣＶＲ	Cockpit Voice Recorder
ＤＦＤＲ	Digital Flight Data Recorder
ＥＥＣ	Engine Electronic Control
ＥＧＴ	Exhaust Gas Temperature
ＦＡＡ	Federal Aviation Administration
ＦＡＲ	Federal Aviation Regulations
ＦＥＷ	Few
ＨＰＣ	High Pressure Compressor
ＨＰＴ	High Pressure Turbine
ＩＧＶ	Inlet Guide Vane
ＬＰＣ	Low Pressure Compressor
ＬＰＴ	Low Pressure Turbine
ＭＡＣ	Mean Aerodynamic Chord
ＭＥＬ	Minimum Equipment List
ＭＥＴＡＲ	Aerodrome Routine Meteorological Report
Ｎ１	Low Pressure Compressor Speed
Ｎ２	High Pressure Compressor Speed
ＮＴＳＢ	National Transportation Safety Board
ＰＦ	Pilot Flying
ＰＮＦ	Pilot Not Flying
ＱＲＣ	Quick Reference Checklist
ＶＳＶ	Variable Stator Vane

Unit conversion

１in=２.５４cm

１ft=０.３０４８m

１lb=０.４５３５kg

１kt=１.８５２km/h

１inHg=３３.８６hPa