

AI2010-1

**AIRCRAFT SERIOUS INCIDENT
INVESTIGATION REPORT**

**AIR INDIA
V T - E P W**

January 29, 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 Air India, Boeing 747-337(COMBI) registration VP-EPW 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

AIR INDIA
BOEING 747-337 (COMBI), VT-EPW (INDIA)
IN THE AIR, APPROXIMATELY 10 KILOMETERS SOUTH OF NARITA
INTERNATIONAL AIRPORT
AT ABOUT 12:38 JST, SEPTEMBER 21, 2008

December 18, 2009

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 |

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

On September 21 (Sunday), 2008, at 12:29 Japan Standard Time (JST: unless otherwise stated all times are indicated in JST), a Boeing 747-337, registered VT-EPW, operated by Air India, took off from Narita International Airport on the Company’s scheduled Flight 307. At about 12:38, while the aircraft was climbing in airspace about 10 km south of Narita International Airport bound for Indira Gandhi International Airport (India), an abnormal noise emanated from the No. 3 engine at an altitude of 15,700 ft, together with an instrument indication showing an abnormality with the engine. The engine in question was then shut down and fuel was jettisoned before the aircraft turned back to Narita International Airport and landed at 13:50.

There were 182 people on board, consisting of the Pilot in Command, 13 other crewmembers and 168 passengers. No one was injured.

1.2 Outline of the Serious Incident Investigation

1.2.1 Investigation Organization

On September 22, 2008, the Aircraft and Railway Accidents Investigation Commission (ARAIC) designated an investigator-in-charge and two other investigators to investigate this serious incident.

1.2.2 Representatives from Foreign Authorities

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

1.2.3 Cooperation

The Japan Aerospace Exploration Agency (JAXA), an independent administrative institution, extended its cooperation in analyzing the fracture surfaces in the low-pressure turbine section of the aircraft’s No. 3 engine.

1.2.4 Implementation of the Investigation

| | |
|---------------------------|--|
| September 23 and 24, 2008 | Interviews, aircraft examination, and investigation of falling objects |
| September 29, 2008 | Examination of onboard documents and engine-related documents |

| | |
|------------------------------------|---|
| September 30 – October 31, 2008 | Analysis of the records of the digital flight data recorder and cockpit voice recorder |
| October 3, 2008 | Engine examination |
| November 18 – 30, 2008 | Engine teardown inspection and examination of engine maintenance records and other relevant documents |
| December 16, 2008 – April 30, 2009 | Analysis of fracture surfaces in the low-pressure turbine section |

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 States

Comments were invited from the participating states.

2. FACTUAL INFORMATION

2.1 History of the Flight

On September 21, 2008, at 12:29, a Boeing 747-337, registered VT-EPW (hereinafter referred to as “the Aircraft”), operated by Air India (hereinafter referred to as “the Company”), took off from Narita International Airport (hereinafter referred to as “the Airport”) on the Company’s scheduled Flight 307.

The flight plan submitted to the Narita Airport Office of the Tokyo Regional Civil Aviation Bureau (hereinafter referred to as “the Airport Office”) is outlined below:

| | |
|-----------------------------------|--|
| Flight rules: | Instrument Flight Rules (IFR) |
| Departure aerodrome: | Narita International Airport |
| Estimated off-block time: | 12:00 |
| Cruising speed: | 508 kt |
| Cruising altitude: | FL320 |
| Route: | HME (Haneda VOR/DME) – KCC (Nagoya VORTAC) – V28 (Airway) – FU (Fukue NDB) – A593 (Airway) – LAMEN (Position reporting point) – (the rest omitted) |
| Destination aerodrome: | Indira Gandhi International Airport |
| Total estimated elapsed time: | 7 h 27 min |
| Fuel load expressed in endurance: | 9 h 49 min |
| Persons on board: | 182 |

The flight crew of the Aircraft consisted of three persons: a Pilot in Command (hereinafter referred to as “the PIC”), a captain-qualified first officer (hereinafter referred to as “the First Officer”) and a flight engineer.

At the time of the serious incident, the PIC was sitting in the left seat as the PF (pilot flying: pilot mainly in charge of flying) and the First Officer was sitting in the right seat as the PNF (pilot not flying: pilot mainly in charge of duties other than flying).

According to the records of air traffic control communications between the Aircraft and the radar approach control facility at the Airport Office (hereinafter referred to as “the Approach”) and between the Aircraft and the area control center at the Tokyo Air Traffic Control Center (hereinafter referred to as “the Tokyo ACC”), the records of the digital flight data recorder (hereinafter referred to as “the DFDR”) and the cockpit voice recorder (hereinafter referred to as “the CVR”), as well as the statements from the flight crewmembers, the history of the flight from the time when the Aircraft took off from the Airport up to the time when the serious incident occurred is as outlined below.

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

- 12:29 The Aircraft took off from Runway 16R of the Airport.
- 12:38:11 There was a loud “clunking” noise (recorded on the CVR) generated in the Aircraft. At 15,700 ft (recorded on the DFDR), the N1*¹ for the Aircraft’s No. 3 engine dropped sharply to 79.0%.
- 12:39:28 The Aircraft contacted the Tokyo ACC requesting permission to fly level at FL200 for five minutes due to a technical trouble.
- 12:39:36 The Tokyo ACC cleared the Aircraft for maintaining FL200.
- 12:43:56 The Aircraft notified the Tokyo ACC that it would return to Narita because of a problem that had developed in the No. 3 engine.
- 12:44:38 The Aircraft requested permission from the Tokyo ACC for clearance for fuel jettisoning and the necessary descent for this purpose.
- 12:46:58 The Aircraft requested the Tokyo ACC to provide radar guidance and altitude assignment for the fuel jettisoning.
- 12:47:30 The Tokyo ACC instructed the Aircraft to change heading to 230° as part of the radar guidance to the fuel jettisoning area.
- 12:50:50 The Aircraft requested permission from the Tokyo ACC to clear an ILS RWY16R procedure to return to the Airport.
- 12:52:04 The Aircraft reported to the Tokyo ACC that fuel jettisoning would take 20 minutes to complete.
- 12:57:58 The Aircraft shut down the No. 3 engine. (Recorded by the DFDR)
- 13:01:37 The Aircraft reported the start of fuel jettisoning at FL180 to the Approach.
- 13:04:07 The Approach asked the Aircraft if the crew intended to declare an emergency.
- 13:04:13 The Aircraft reported to the Approach that it did not require any assistance, stating that the Aircraft would be able to land normally even though the No. 3 engine was shut down.
- 13:24:16 The Aircraft reported to the Approach that fuel jettisoning was completed and that it was ready for an approach.
- 13:24:26 The Aircraft reported to the Approach that it was prepared to start an approach, requested radar guidance, and then started the approach.
- 13:50 The Aircraft landed normally on Runway 16R of the Airport.

2.1.2 History of the Flight Based on the Statements of the Crewmembers

(1) PIC

On the day of the serious incident, I went to the Aircraft to perform an overall pre-flight inspection on it prior to the departure. The inspection did not reveal any abnormalities.

I took the left seat as the PF and the First Officer sat in the right seat as the PNF.

*¹ “N1” is the rotational speed of the engine fan, low-pressure compressor and low-pressure turbine. For the engines of the Aircraft, “N1” is indicated as 100% for each engine when running at 3,430 rpm, the speed approximately corresponding to the maximum thrust speed.

I then started the engines and carried out various instrument checks and confirmation without finding anything abnormal. During the pushback from the spot and taxiing as well as during the subsequent takeoff roll and takeoff procedure, I did not find anything abnormal.

At about 12:29, we took off from Runway 16R of the Airport. While we were climbing via Narita Reversal Eight Departure, a standard instrument departure of the Airport, I heard a “clunk” at about FL180, which came from behind on the right side.

I only heard that noise once.

I looked at the engine instruments, and found that the N1 for the No. 1, No. 2 and No. 4 engines were all about 102.5%, that is climbing power. However, the N1 for the No. 3 engine had dropped to 68%, so I slowly moved the thrust lever for the No. 3 engine back to idle.

I subsequently stopped climbing at FL200, leveled out at the airspeed of 300 kt, and then slowly advanced the No. 3 engine thrust lever, but the N1 stayed at 68% without showing any change.

The inspection performed at that time revealed that the N1, N2, EGT*² and FUEL FLOW*³ for the No. 1, No. 2 and No. 4 engines were all normal, whereas the N1 for only the No. 3 engine had dropped.

I then tentatively advanced the No. 3 engine thrust lever again slowly, but the N1 still stayed between 60% and 70%. Consequently, I shut down the No. 3 engine.

As it was evident that a problem had developed in the No. 3 engine, I considered it necessary to return to the Airport for inspection after landing, and made the decision to do so.

I made an announcement to the passengers, saying, “Due to a technical trouble, we will be returning to the Airport.”

After this, I requested the Tokyo ACC to indicate the fuel jettisoning area, and the Tokyo ACC instructed by saying that it would provide radar guidance as the area was located within the Narita Approach.

The Approach asked, “Do you intend to declare an emergency?”. To this question, I answered that we did not intend to declare an emergency, as the Aircraft had four engines and I judged that one inoperative engine would not create a problem and would still allow the Aircraft to make a normal landing.

Aided by radar guidance, we landed normally on Runway 16R at about 13:50. After the landing, we taxied the Aircraft on its own power to Spot 506.

(2) First Officer

I was in the right seat as the PNF.

We were originally to climb up to FL320, but when we heard a vroom coming from the right hand side aft of us at about FL180 during the climb, we decided to limit the climb to FL200 and continue flying level at FL200 for a certain period of time to

*² “EGT” stands for engine exhaust gas temperature as measured at the turbine outlet.

*³ “FUEL FLOW” means the fuel flow rate, in which the amount of fuel delivered in units of time is expressed by weight.

check for problems that might be present elsewhere. We found nothing wrong except for the N1 of the No. 3 engine that had dropped to an excessively low level. I heard the abnormal noise only once.

At that time, the No. 1, No. 2 and No. 4 engines maintained climbing power of about 102%.

We then decided to return to the Airport with the No. 3 engine shut down. The PIC made an announcement to the passengers saying, “We will be returning to the Airport due to a technical trouble.”

(3) Flight engineer

Upon occurrence of the abnormal condition, I checked the instrument readings and found that the EGT of the No. 1, No. 2, No. 3 and No. 4 engines were normal.

I also found that the FUEL FLOW for the No. 1, No. 2, No. 3 and No. 4 engines were normal.

The N1 were normal for the No. 1, No. 2 and No. 4 engines but had dropped to as low as 60–70% for the No. 3 engine alone.

The vibration indicator*4 showed no fluctuations.

The serious incident occurred at about 12:38 in the air about 10 km south of Narita International Airport. (Latitude 35°40'25"N, Longitude 140°21'28"E)

(See Figure 1 – Estimated Flight Path; Figure 3 – Three Angle View of Boeing 747-337; Figure 4 – DFDR Records; and Photo 1 – Serious Incident Aircraft.)

2.2 Injuries to Persons

No persons were injured.

2.3 Damage to the Aircraft

- (1) The No. 3 engine low-pressure turbine (hereinafter referred to as “the LPT”) experienced mechanical damage.
- (2) The skin panel and wing access door on the lower surface of the right wing and the inner panel of the No. 3 engine were scratched.

(See Figure 2 – No. 3 Engine LPT.)

2.4 Other Damage

Fragments of LPT blades and nozzle guide vanes (hereinafter referred to as “NGV”^{*5}) fell onto three passenger cars parked directly beneath the Aircraft’s flight path, and some fragments stuck in the cars and damaged them.

(See Photo 10 – Damaged Car.)

*4 The “vibration indicator” is an instrument that senses and indicates the vibration level of the fan, compressor and turbine sections of a jet engine.

*5 The “NGV” is a stator located between the turbine blades of two adjoining stages of the engine. Each NGV is attached to the engine outer casing and does not rotate.

2.5 Personnel Information

- (1) PIC Male, Age 48
Rendering valid of license *⁶ (issued by the United States of America)
Airline Transport Pilot Certificate (Airplane) August 21, 2004
Type rating for Boeing 747
Class 1 Aviation Medical Certificate
Validity November 30, 2008
Total flight time 12,600 h 00 min
Flight time in the last 30 days 49 h 20 min
Total flight time on the type of aircraft 9,000 h 00 min
Flight time on the type of aircraft in the last 30 days 49 h 20 min
- (2) First Officer Male, Age 61
Airline Transport Pilot Certificate (Airplane) (issued by India) July 23, 1999
Type rating for Boeing 747
Class 1 Aviation Medical Certificate
Validity November 26, 2008
Total flight time 13,000 h 00 min
Flight time in the last 30 days 25 h 35 min
Total flight time on the type of aircraft 10,000 h 00 min
Flight time on the type of aircraft in the last 30 days 25 h 35 min
- (3) Flight Engineer Male, Age 58
Flight Engineer Certificate (Airplane) (issued by India) October 3, 1979
Type rating for Boeing 747
Class 1 Aviation Medical Certificate
Validity October 8, 2008
Total flight time 12,707 h 15 min
Flight time in the last 30 days 30 h 40 min
Total flight time on the type of aircraft 9,182 h 00 min
Flight time on the type of aircraft in the last 30 days 30 h 40 min

2.6 Aircraft Information

2.6.1 Aircraft

| | |
|------------------------------|------------------------|
| Type | Boeing 747-337 (Combi) |
| Serial number | 24159 |
| Year of manufacture | 1988 |
| Certificate of airworthiness | No. 1916 |
| Validity | December 12, 2008 |
| Total flight time | 52,779 h 00 min |

*⁶ According to Annex 1 to the Convention on International Civil Aviation, “rendering a license valid” means the approval by a convention contracting state of a license issued by another convention contracting state as being equivalent in validity to the corresponding license issued by the former state and granting a certificate for the necessary items thereof to the licensee under the relevant former state’s law(s).

Flight time since last periodical check

(A and 2A checks on July 15, 2008)

74 h 00 min

(See Figure 3 – Three Angle View of Boeing 747-337)

2.6.2 Engine

| | |
|--|-----------------------------|
| (1) No. 1 engine | |
| Type | General Electric CF6-80C2B1 |
| Serial number | 690-163 |
| Date of manufacture | February 1987 |
| Total time in service | 44,682 h 00 min |
| Total cycles in service | 16,251 |
| (2) No. 2 engine | |
| Type | General Electric CF6-80C2B1 |
| Serial number | 690-121 |
| Date of manufacture | May 1986 |
| Total time in service | 47,435 h 00 min |
| Total cycles in service | 17,313 |
| (3) No. 3 engine | |
| Type | General Electric CF6-80C2B1 |
| Serial number | 690-124 |
| Date of manufacture | June 1986 |
| Total time in service | 43,069 h 00 min |
| Total cycles in service | 13,740 |
| Time in service since last maintenance (in February 2006) | 6,143 h 00 min |
| Cycles in service since last maintenance (in February 2006) | 1,442 |
| Reinstallation on the Aircraft | February 4, 2006 |
| (4) No. 4 engine | |
| Type | General Electric CF6-80C2B1 |
| Serial number | 690-314 |
| Date of manufacture | November 1988 |
| Total time in service | 41,315 h 00 min |
| Total cycles in service | 12,642 |

(See Figure 2 – No. 3 Engine LPT)

2.6.3 Fuel and Lubricating Oil

The Aircraft used aviation fuel Jet A-1 as the fuel and Mobile Jet Oil II as the lubricating oil.

2.6.4 Weight and Balance

When the serious incident occurred, the Aircraft's weight is estimated to have been 728,923 lbs and the position of the center of gravity is estimated to have been 20.0% mean aerodynamic chord (MAC), both of which are estimated to have been within the allowable range (i.e., maximum takeoff weight of 832,998 lbs, maximum landing weight of 628,100 lbs and 15.5 to 25.3% MAC corresponding to the weight of the Aircraft at the time of the serious incident).

The weight of the Aircraft at the time of the landing was 589,582 lbs as the weight after fuel jettisoning.

2.7 Meteorological Information

Aeronautical weather observations for Narita International Airport, located about 10 km north of the serious incident site, around the time of the serious incident were as follows:

12:30 Wind direction 130°, Wind velocity 8 kt, Wind direction variable 100°–160°,
Visibility 10 km or more,
Cloud: Amount 1/8, Type Cumulus, Ceiling 1,500 ft
Amount 4/8, Type Cumulus, Ceiling 2,500 ft
Amount 7/8, Type Stratocumulus, Ceiling 5,000 ft
Temperature 25°C, Dew point 21°C,
Altimeter setting (QNH) 29.79 inHg,
Landing forecast (TREND) No significant change

2.8 Information on the DFDR and CVR

The Aircraft was equipped with a DFDR (part number: 2100-4043-00) manufactured by L-3 Communications of the United States of America and a CVR (part number: 980-6022-001) manufactured by Honeywell of the United States of America.

The DFDR and the CVR retained the engine data and voice records relevant to the serious incident.

2.9 Details of the Damage to the Aircraft

The airframe examination conducted after the serious incident revealed small holes and scratches on the right wing bottom skin panel, the wing access door and the area around the No. 3 engine inner panel.

The LPT is a five-stage, axial-flow turbine consisting of five stator and rotor combinations with the stator on the upstream side in each stage. The condition of the damage to the main parts of the No. 3 engine LPT was as follows:

- (1) First LPT stage (hereinafter referred to as "STG-1")

The STG-1 stator consists of 13 segments, each of which is composed of six NGVs (hereinafter referred to as a "Vane Segment") and is numbered from 1 to 13.

Of these Vane Segments, the No. 2 Vane Segment had cracks in two of its NGVs.

There was no damage to the turbine blades.

- (2) Second LPT stage (hereinafter referred to as "STG-2")

The STG-2 stator consists of 16 Vane Segments while the rotor consists of 124 turbine

blades.

- ① All six NGVs of the No. 3 Vane Segment were found to have fractured at sections near their outer ends and had become lost. The inner platform of the Vane Segment was missing.
 - ② One NGV of the No. 1 Vane Segment had cracks. Other NGVs were also severely damaged.
 - ③ The 124 turbine blades on the entire circumference were damaged. One of these blades was found to have fractured at its root attached to the LPT disc.
- (3) The turbine blades and the NGVs of the third LPT stage (hereinafter referred to as “STG-3”) to the fifth LPT stage (hereinafter referred to as “STG-5”) were severely damaged.
 - (4) The LPT casing had numerous holes and cracks that were apparently caused by turbine blades and other objects having struck against it, but did not pass through the LPT case. The liberated blades discharged axially from the engine exhaust.

(See Figure 2 – No. 3 Engine LPT; Photo 2 – Cracked No. 2 Vane Segment NGVs of LPT STG-1; Photo 3 – Fractured No. 3 Vane Segment NGVs of LPT STG-2; Photo 4 – Fractured Turbine Blades of LPT STG-2; Photo 5 – Fractured Turbine Blades of LPT STG-4; and Photo 6 – Damaged LPT Casing of No. 3 Engine.)

2.10 Tests and Researches for Fact-Finding

2.10.1 Time in Service and Other Information on STG-1 and STG-2 NGVs of No. 3 Engine

- (1) According to the maintenance records kept by the Company, the No. 2 Vane Segment NGVs (P/N 9367M81G31) of the STG-1 had been used for 10,803 hours and 2,064 cycles.

All 13 Vane Segments of the STG-1 had been replaced during the maintenance carried out in July 2003.

During the maintenance conducted in February 2006, the No. 2 Vane Segment was judged to be normal and was not replaced; therefore, the No. 2 Vane Segment which was replaced at the time of the maintenance in July 2003 had been used since then.

- (2) The No. 3 Vane Segment NGVs (P/N 9367M82G14) and the No. 1 Vane Segment NGVs (P/N 9367M82G14) of the STG-2 had been used for 10,803 hours and 2,064 cycles.

During the maintenance in July 2003, nine of the 16 Vane Segments of the STG-2 had been replaced.

At that time, both No. 3 and No. 1 Vane Segments had been replaced with ones of P/N 9367M82G14.

Afterwards, during the maintenance conducted in February 2006, eight Vane Segments had been replaced, not including the No. 3 and No. 1 Vane Segments that had been judged to be normal.

Therefore, the No. 3 and No. 1 Vane Segments which were replaced at the time of the maintenance in July 2003 had been used since then.

2.10.2 Detailed Analysis of NGV Fracture Surfaces of the No. 3 Engine LPT

Detailed analysis was conducted on fracture surfaces of the LPT NGVs of the No. 3 engine with cooperation extended by JAXA. The results are summarized below.

Fracture surfaces of the six NGVs of the STG-2 No. 3 Vane Segment and the cracks in both STG-2 No. 1 Vane Segment NGVs and STG-1 No. 2 Vane Segment NGVs were subjected to fracture analysis, which was conducted using an optical microscope, SEM (scanning electron microscope), EDAX (wavelength dispersive X-ray analyzer produced by EDAX), and other appropriate means. The results are described below.

- (1) Analysis of fracture surfaces using an optical microscope (model VHX-200) and by visual inspection

The fracture surfaces had become corroded due to oxidization and some of them showed signs of stress corrosion cracking*⁷ that had developed in the grain boundaries*⁸.

Multiple cracks that started at different points joined one another to present the appearance of branching fracture, which resulted in the through-wall cracking.

- (2) Oxygen concentration gradient analysis using an EDAX (Energy Dispersive X-ray Microanalysis manufactured by EDAX)

The NGVs have an oxidation resistant coating on the outer wall surfaces, but not on the inner wall surfaces. As this allowed the assumption that oxidation would have progressed from the inner wall surface toward the outer wall surface of each NGV, analysis was conducted to determine the oxygen concentration gradient across a section of the NGV. The results showed that oxidation of too high a degree to determine the oxygen concentration gradient had developed in the through-wall direction of the NGV.

Material analysis conducted on the NGVs showed that the only alloy material was Rene*⁹ 77.

- (3) Inner wall surface examination on cut NGVs

Each of the NGVs had an oxidation resistant coating on the outer surface, whereas the inner wall surfaces were covered with black, oxidized film that was in an easily separated condition.

Under the inner wall surfaces with no oxidation resistant coating, the parent metal showed severe intergranular corrosion*¹⁰ and intergranular oxidation*¹¹ and easily broke into fragments.

*⁷ “Stress corrosion cracking” refers to brittle fracture that occurs in a metallic material placed in a specific corrosive environment and under tensile stress for a certain period of time; the fracture occurs at a smaller amount of stress than the stress at which the same material fractures when it is placed in a non-corrosive environment.

*⁸ “Grain boundary” is the boundary between adjoining crystal grains, which appears as a web in structural observation using an optical microscope.

*⁹ “Rene” is the name of a heat-resistant alloy.

*¹⁰ “Intergranular corrosion” refers to the intense development of oxidation that is caused by precipitation produced in a grain boundary, which deprives the vicinity of the grain boundary of the element thus precipitated and eventually accelerates corrosion.

*¹¹ “Intergranular oxidation” is the oxidation that develops during heat treatment of a metallic product in the grain boundaries of the product’s surface layer due to the oxygen present in the heat treatment atmosphere.

(See Photo 7 – Fracture Surface of LPT STG-2 NGV and Photo 9 – Intergranular Corrosion and Intergranular Oxidation of LPT STG-2 NGV Inner Wall Surfaces.)

2.10.3 Examination of the STG-2 Turbine Blade Fractured at Its Root Attached to the LPT Disc

The root portion of the STG-2 turbine blade in question had a deep dent which appeared to be impact damage on the leading edge. The shape of the dent matched the shape of the inner platform of the STG-2 No. 3 Vane Segment NGVs.

(See Photo 4 – Fractured Turbine Blades of LPT STG-2 and Photo 8 – Impact Damage on LPT STG-2 Turbine Blade.)

2.10.4 Examination into the Progress of Breakage in STG-3 to STG-5

As a result of the STG-2 NGVs having fractured and liberated, the turbine blades of the STG-3 to STG-5 had fractured at their roots attached to the LPT discs.

The NGVs of the STG-3 to STG-5 were also severely damaged, with some portions missing. (See Photo 5 – Fractured Turbine Blades of LPT STG-4.)

2.11 Additional Information

2.11.1 Service Bulletin Issued by the Engine Manufacturer

General Electric (GE), the manufacturer of the engines of the Aircraft, issued Service Bulletin CF6-80C2 S/B 72-1222, dated June 16, 2006, which contained the following items of information, intended to improve the overall reliability and durability of the engines. (Excerpts)

(1) *Condition:*

The current stage 1 and stage 2 LPT nozzles have experienced some internal airfoil cavity corrosion and intergranular oxidation (IGO) that has led to through wall cracks and fragmentation of airfoils.

(2) *Cause:*

The stage 1 and stage 2 LPT nozzle internal airfoil cavities do not have an environmental protection coating and are susceptible to degradation from corrosion and IGO. The degradation can affect the airfoil parent metal integrity with the mechanical/thermal stresses leading to cracking.

(3) *Improvement:*

Incorporation of an internal environmental protection coating will improve the reliability and durability of the stage 1 and stage 2 LPT nozzles.

(4) *Effectivity and Description:*

The new/reworked Stage 1 LPT nozzle part numbers are 2101M69G01 – G21, and the new/reworked Stage 2 LPT nozzle part numbers are 2101M71G01 – G08.

(5) *Compliance:*

GE recommends that you do this Service Bulletin when the STG-1 and STG-2 LPT nozzles are routed for repair.

2.11.2 Maintenance Criteria for LPT NGVs

(1) Maintenance requirements established by the Company

The Company established a customized “Workscope Planning Guide” for the LPT NGV maintenance based on the engine manufacturer’s original “Workscope Planning Guide,” and had been conducting maintenance according to the guide as follows:

- Visual inspection is conducted on an “on-condition maintenance”^{*12} basis.
- No service life limit is established for NGVs.

(2) Maintenance work conducted by the Company

The Company had carried out maintenance work on the engine that had been removed from the Aircraft for a certain period of time and taken to the shop. The maintenance work included replacement of LPT section components and other work based on the engine manual.

However, the Company had not conducted maintenance for the LPT NGVs of the engine since February 2006 and did not carry out the Service Bulletin (CF6-80C2 S/B 72-1222). GE Aviation Service Bulletin (CF6-80C2 S/B 72-1222) was issued June 16, 2006.

^{*12} “On-condition maintenance” refers to the practice in which maintenance is performed not depending on pre-established service time limits but rather on the results of engine quality monitoring using various inspection methods. The engine receives necessary maintenance after being removed from the airframe depending on the monitoring results.

3. ANALYSIS

3.1 Crew Qualifications

The PIC, the First Officer and the flight engineer held both 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. Based on the statements of the flight crewmembers and the maintenance records of the Aircraft, it is considered highly probable that there were no problems with the Aircraft up to the moment that the serious incident occurred.

3.3 Contribution of Meteorological Conditions

It is considered highly probable that the meteorological conditions prevailing at the time of the serious incident had not any relevance to the occurrence of the incident.

3.4 Time of Occurrence of the No. 3 Engine Abnormality during the Climb after Takeoff

Based on the following, it is considered highly probable that the occurrence of the engine damage coincided with the generation of abnormal noise from the engine at 15,700 ft during the climb.

- (1) The DFDR records described in 2.1.1 show that, at 12:38:11 while the Aircraft was at 15,700 ft during its climb, the N1 for the No. 3 engine dropped sharply to 79.0%. The CVR recorded a loud “clunking” noise generated at that time.
- (2) The statements from the PIC and the First Officer described in 2.1.2 indicate that a “clunking” noise was heard coming from behind on the right side at about 18,000 ft during the climb after takeoff and the N1 dropped to 68% and that, following the drop in N1 to 68%, the No. 3 engine thrust lever, which had until then been retarded, was advanced but this did not cause any change, so the No. 3 engine was shut down.

3.5 Factors Contributing to the Fracture of No. 3 Vane Segment NGVs and Other Parts in LPT STG-2

As described in 2.10.2 (1) – (3), the No. 3 and No. 1 Vane Segment NGVs in STG-2 and the No. 2 Vane Segment NGVs in STG-1 had an oxidation resistant coating on the outer surfaces but not on the inner wall surfaces.

As suggested by this fact, an examination was conducted by cutting the broken pieces and cracked areas of the NGVs, which revealed that the inner wall surfaces of the NGVs were covered with black oxide film that appeared easy to separate and that severe intergranular corrosion had developed in the parent metal.

Precipitation that forms compounds tends to occur around the grain boundaries. If chromium carbide is formed from precipitation, the grain boundaries are deprived of chromium, an oxidation

resistant material, and become more susceptible to oxidation corrosion. For this reason, it is considered highly probable that developing intergranular corrosion accelerated the degradation and strength reduction of the material, and caused cracking from the inner surface of the blade, eventually resulting in a fracture.

3.6 Process of Fracture of the LPT STG-2 Turbine Blade

The STG-2 turbine blade that had fractured at its root attached to the LPT disc had a deep dent which appeared to be an impact damage at the leading edge.

As described in 2.10.3, the shape of the dent matched the shape of the inner platform of the No. 3 Vane Segment NGVs that had fractured become liberated and were not recovered. It is therefore considered highly probable that the inner platform became detached at the same time as the fracture of the No. 3 Vane Segment NGVs, striking high-speed rotating turbine blades and breaking the turbine blade in question.

3.7 Process of Breakage of the LPT STG-3 to STG-5

With regard to the fracture of the turbine blades on STG-3 to STG-5, which took place in all of the blades near their roots attached to the LPT discs, and the damage to the NGVs of these stages, it is considered highly probable that, as described in 2.10.4, the STG-2 NGVs having fractured and liberated, struck against the STG-2 turbine blades causing secondary breakage, and the secondary breakage expanded further as the broken pieces continued striking against the turbine blades and NGVs of the downstream stages.

3.8 Measures to Alleviate Damage and Prevent Recurrence of Turbine Breakage

As described in 2.11.1, the Service Bulletin dated June 16, 2006, issued by the engine manufacturer, noted that the internal airfoil cavities of the LPT STG-1 and STG-2 NGVs did not have an environmental protection coating and were susceptible to degradation from intergranular oxidation and intergranular corrosion, that had led to through wall cracks and fragmentation of airfoils, and advised that replacing the NGVs with ones having an oxidation resistant coating on the inner wall surfaces would improve the reliability and durability of the nozzles. However, after receiving the Service Bulletin, the Company did not have scheduled maintenance of NGVs of the engine nor did they replace any NGVs.

The approved engine maintenance plan for the CF6-80C2 engine is based on Condition Maintenance.

There are no hard time limits except for rotating part lives.

Judging from the above, it is considered probable that the engine manufacturer should have made clear the appropriate timing to replace NGVs for the operator to ensure overall engine reliability and durability.

3.9 Process of Events Resulting in Damage to the Lower Surface of the Aircraft's Right Wing

With regard to the numerous small holes and scratches found on the right wing access door and the inner panel of the No. 3 engine, it is considered highly probable that the STG-2 NGVs

having fractured and separated struck against the STG-2 turbine blades causing secondary breakage, which in turn caused the turbine blades and NGVs of the downstream stages to fracture as described in 3.7, and then the fragments of the LPT blades and NGVs discharged from the engine exhaust with some of them striking the right wing access door and the No. 3 engine's inner panel and surrounding areas.

3.10 Effects Caused by the Fracture of Turbine Blades and NGVs on Ground Objects

It is considered highly probable that, as a result of the secondary breakage as described in 3.9, the fragments of the LPT blades and NGVs discharged from the engine exhaust outlet were scattered in the air. Then, as described in 2.4, some of the broken, falling pieces of turbine blades stuck in the passenger cars parked directly beneath the Aircraft's flight path and damaged them.

4. PROBABLE CAUSE

It is considered highly probable that this serious incident occurred through the following process. While the Aircraft was climbing after takeoff, nozzle guide vanes of the No. 3 engine LPT STG-2 separated and scattered after fracturing due to intergranular corrosion, and this caused the breakage of the nozzle guide vanes and turbine blades of the downstream stages and eventually damaged the engine.

With regard to the fracture of the nozzle guide vanes due to intergranular corrosion, it is considered highly probable that the inner wall surfaces of the nozzle guide vanes that, unlike the outer surfaces, had no oxidation resistant coating were susceptible to oxidation and corrosion in the grain boundaries, and this led to progressive material degradation and decrease in strength, ultimately resulting in fracture of the vanes starting from the inside walls.

Figure 1 Estimated Flight Path

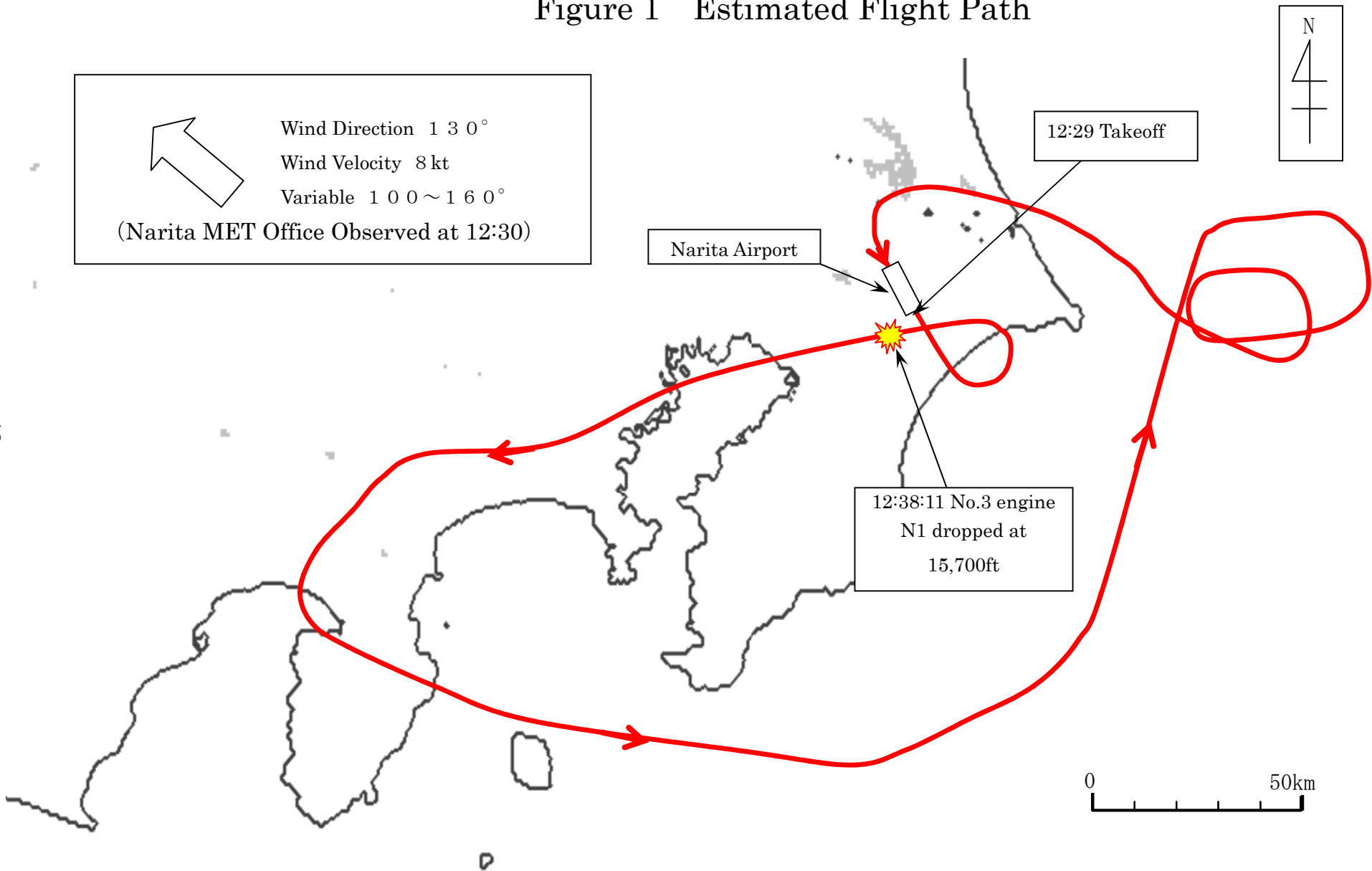


Figure 2 No.3 Engine LPT

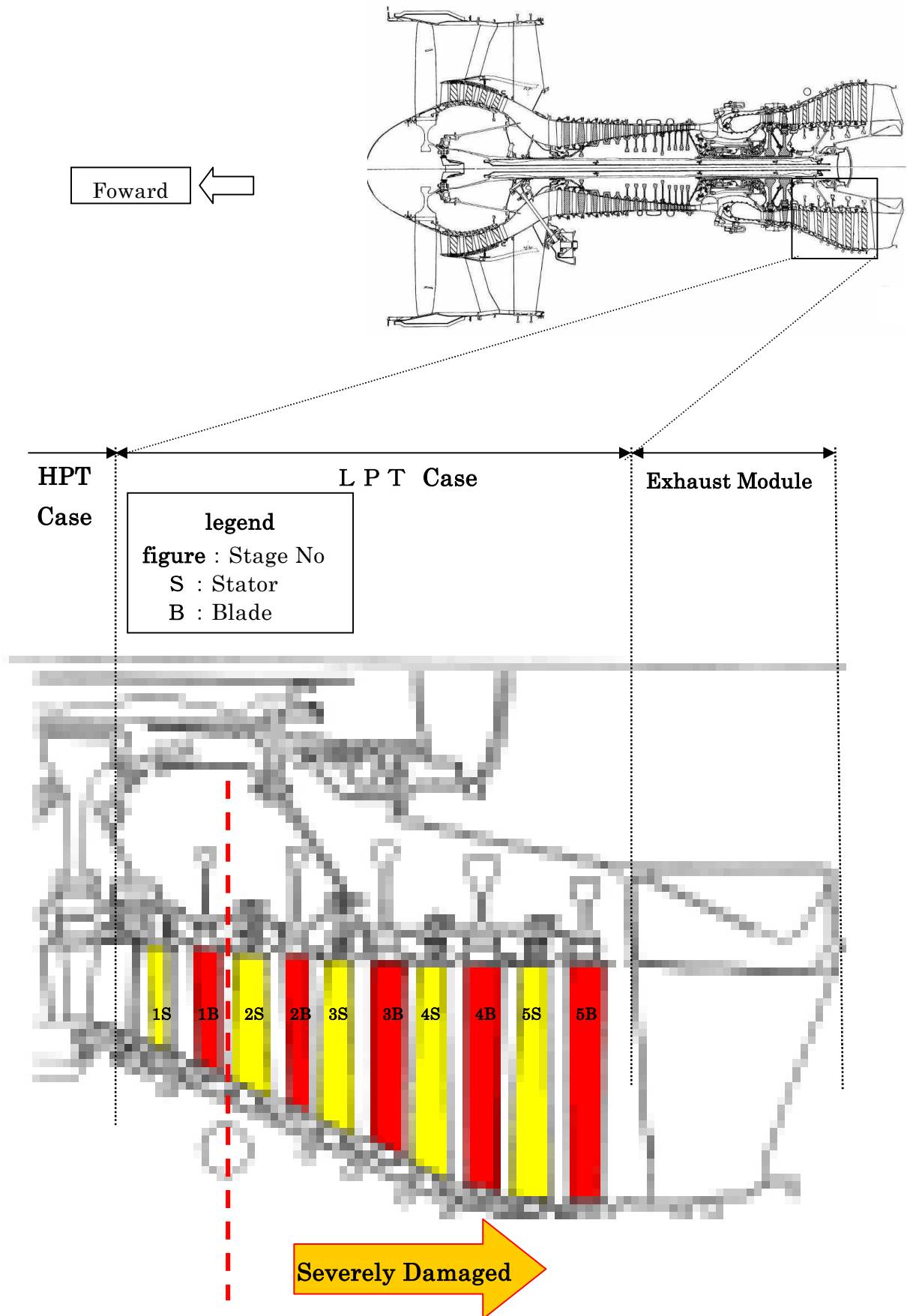


Figure 3 Three Angle View of Boeing 747-337

Unit : m

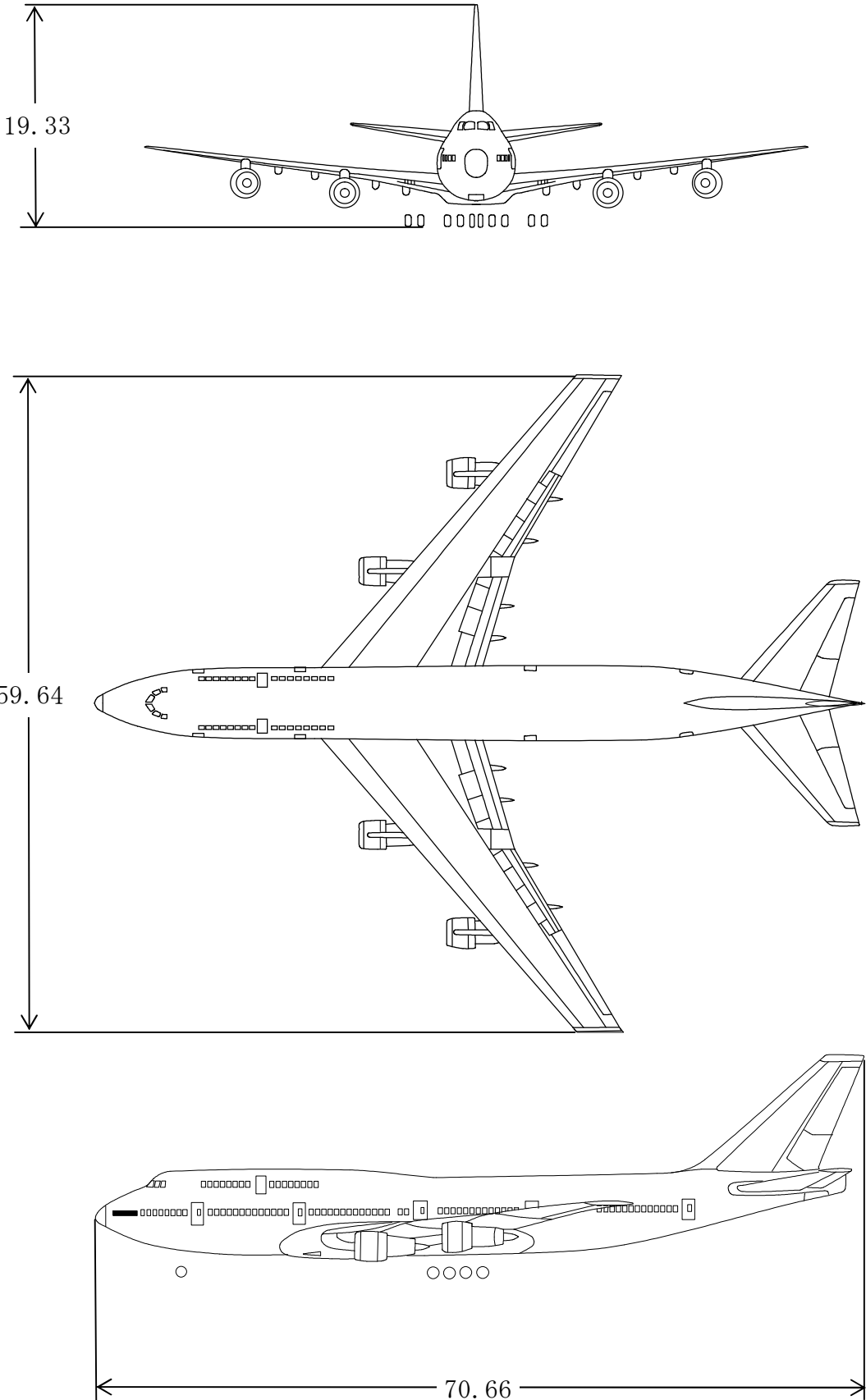


Figure 4 DFDR Records

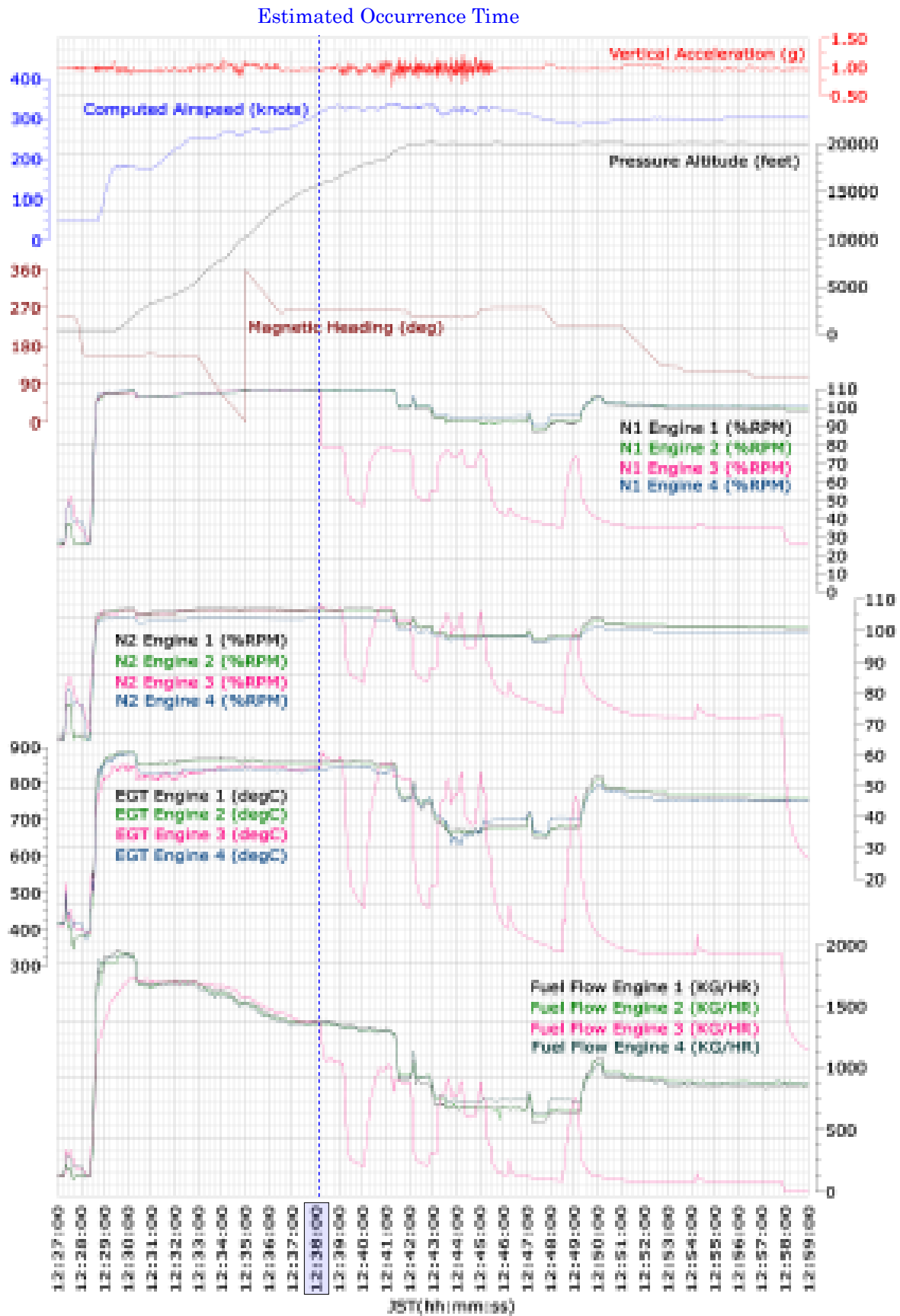


Photo 1 Serious Incident Aircraft



Photo 2 Cracked No.2 Vane Segment NGVs of LPT
STG-1

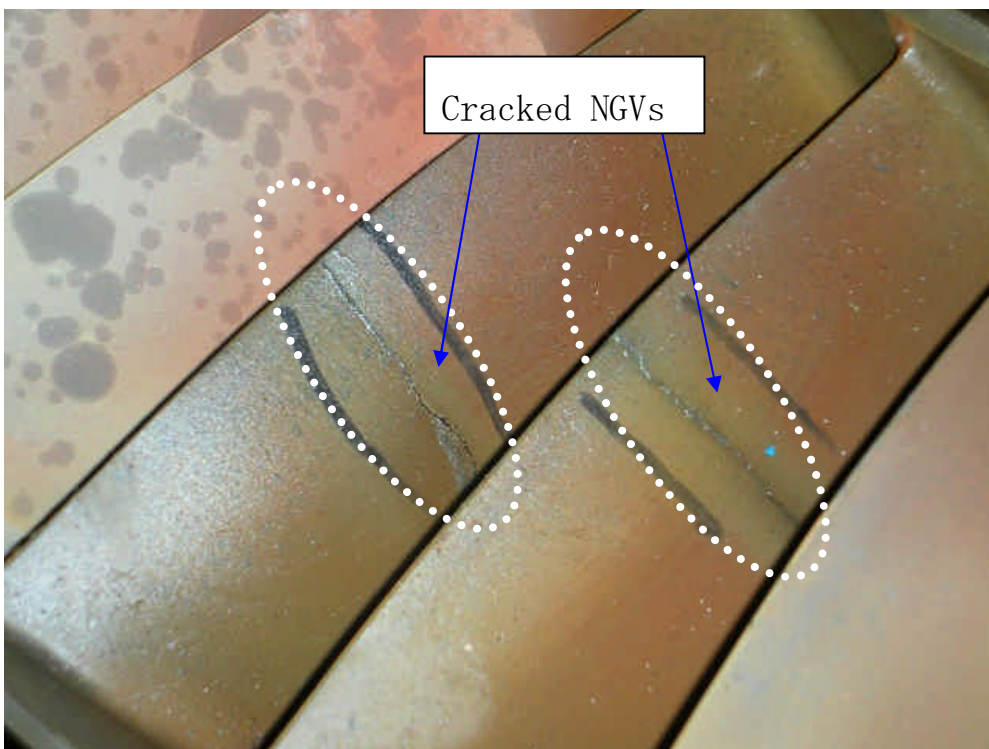


Photo 3 Fractured No.3 Vane Segment NGVs of LPT STG-2

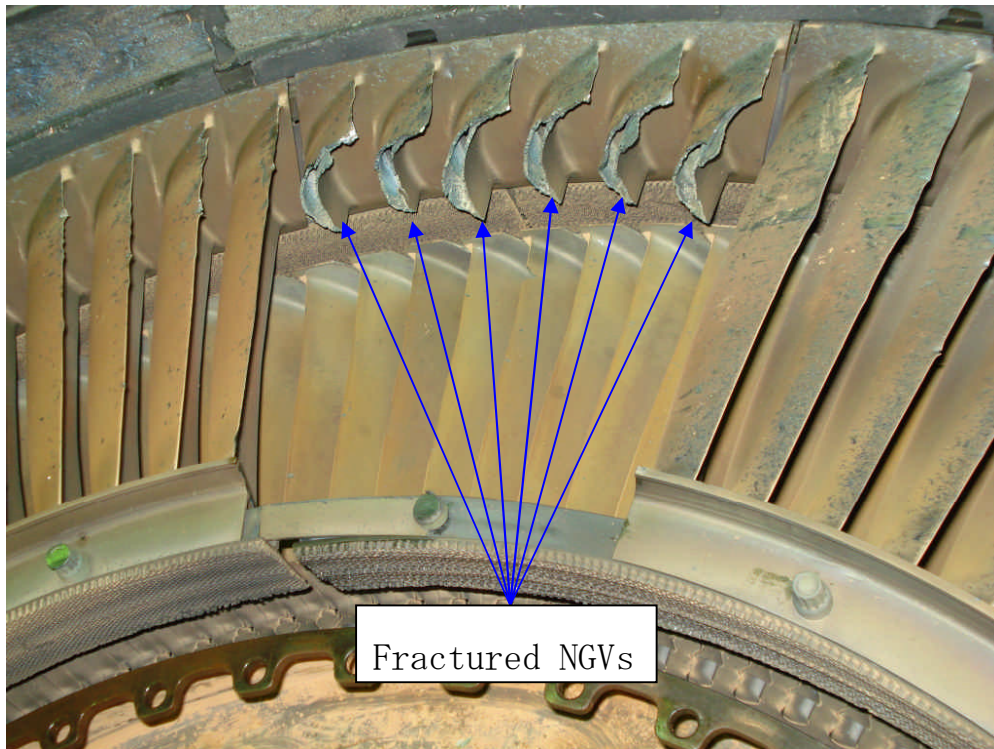


Photo 4 Fractured Turbine Blades of LPT STG-2



Photo 5 Fractured Turbine Blades of LPT STG-4

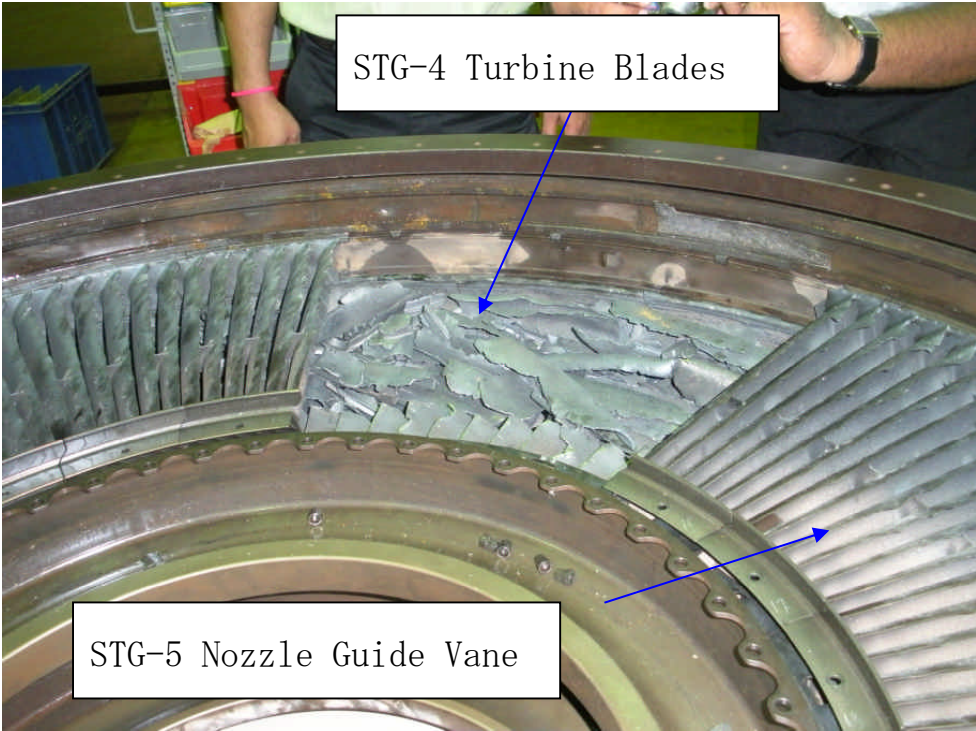


Photo 6 Damaged LPT Casing of No.3 Engine



Photo 7 Fractured Surface of LPT STG-2 NGV

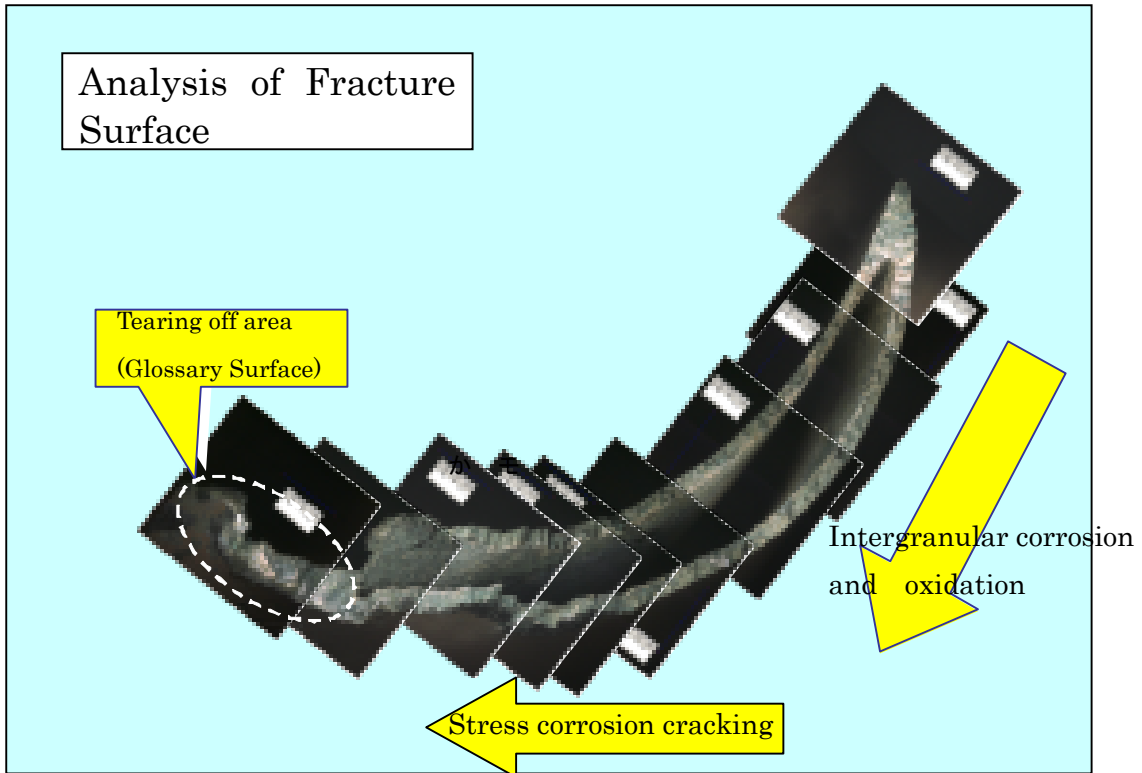


Photo 8 Impact Damage on LPT STG-2 Turbine Blade

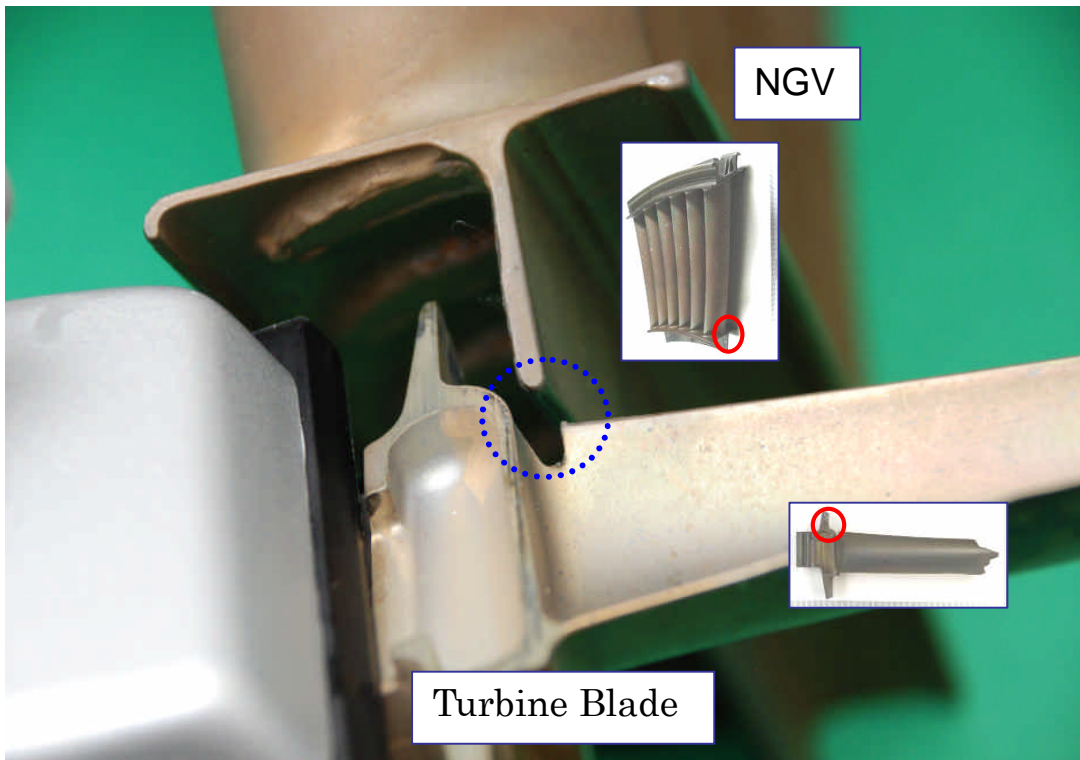


Photo 9 Intergranular Corrosion and Intergranular Oxidation of LPT STG-2 NGV Inner Wall Surfaces

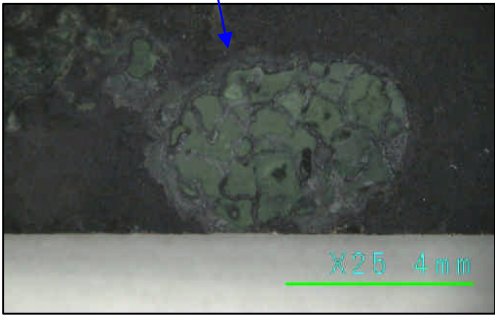
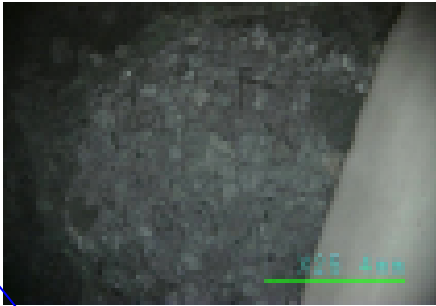
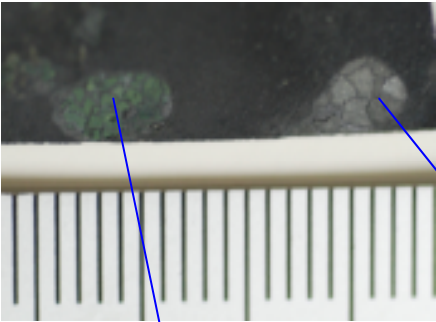


Photo 10 Damaged Car

