AA2006-3

AIRCRAFT ACCIDENT INVESTIGATION REPORT

JAPAN AIRSYSTEM FLIGHT 979
DOUGLAS DC-9-81, JA8297
STOPPED ON RUNWAY DUE TO LEFT MAIN LANDING GEAR COLLAPSE
JANUARY 1, 2004

July 28, 2006

Aircraft and Railway Accidents Investigation Commission
Ministry of Land, Infrastructure and Transport

The investigation for this report was conducted by Aircraft and Railway Accidents Investigation Commission, ARAIC, about the aircraft accident of Japan Air system Flight 979 Douglas DC-9-81 in accordance with Aircraft and Railway Accidents Investigation Commission Establishment Law and Annex 13 to the Convention of International Civil Aviation for the purpose of determining cause of the aircraft accident and contributing to the prevention of accidents and not for the purpose of blaming responsibility of the accident.

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

Junzo Sato,
Chairman,
Aircraft and Railway Accidents Investigation Commission

(ABBREVIATION)

Abbreviated words used in this report are as follows:

ABS	:	Automatic Brake System
AD	:	Airworthiness Directive
CA	:	Cabin Attendant
CMM	:	Component Maintenance Manual
CVR	:	Cockpit Voice Recorder
DFDR	:	Digital Flight Data Recorder
EPR	:	Engine Pressure Ratio
FAA	:	Federal Aviation Administration
FSC	:	Flight Service Center
GND	:	Ground
IAS	:	Indicated Air Speed
ksi	:	kilo pounds per square inch
kt	:	knot
NAS	:	National Aerospace Standard
NDI	:	Non Destructive Inspection
NIMS	:	National Institute for Materials Science
NTSB	:	National Transportation Safety Board
NTT	:	Nippon Telegraph and Telephone Corporation
MAC	:	Mean Aerodynamic Chord
MIN	:	Minimum
MPa	:	Mega-Pascal
PA	:	Passenger Address
PF	:	Pilot Flying
PIC	:	Pilot in Command
PNF	:	Pilot not flying
RTO	:	Rejected Take Off
SB	:	Service Bulletin
V_{REF}	:	Landing Reference Speed
V_{TG}	:	Target Speed for Final Approach

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DOUGLAS DC-9-81, JA8297
STOPPED ON RUNWAY DUE TO LEFT MAIN LANDING GEAR COLLAPSE
AT ABOUT 16:24 JST, JANUARY 1, 2004

June 21, 2006

Decision by the Aircraft and Railway Accidents Investigation Commission

(Aviation Sub-committee Meeting)

Chairman	Junzo Sato
Member	Yukio Kusuki
Member	Susumu Kato
Member	Noboru Toyooka
Member	Yukiko Kakimoto
Member	Akiko Matsuo

1. PROCESS AND PROGRESS OF THE ACCIDENT INVESTIGATION

1.1 Summary of the Accident

On Thursday, January 1, 2004, Japan Air System (JAS) Douglas DC-9-81, JA8297, which was being operated by Harlequin Air as JAS scheduled passenger flight 979, took off from Kagoshima Airport at 15:35 JST and flew to Tokunoshima Airport. On landing at Tokunoshima Airport, the aircraft's left main landing gear (MLG) collapsed during rollout and its left wing tip contacted the ground. The aircraft came to a stop on the runway at around 16:24.

There were 169 persons on board flight 979 — 163 passengers (including seven infants), the captain and five other crewmembers. Three passengers sustained minor injuries.

The aircraft sustained substantial damage, but there was no outbreak of fire.

1.2 Outline of the Accident Investigation

1.2.1 Organization of the Investigation

On January 4, 2004, the Aircraft and Railway Accident Investigation Commission (ARAIC) received the notification of the accident from the Minister for Land, Infrastructure and Transport, then assigned an Investigator-in-Charge and two investigators for the accident. On April 1, 2004,ARAIC assigned an additional investigator.

1.2.2 Cooperation by Foreign Authority

An accredited representative of the United States, the state of design and manufacture of the aircraft, participated in the investigation.

1.2.3 Implementation of the Investigation

The investigation proceeded as follows.

January 5–9, 2004	On-site investigation and interviews.
January 9–March 9, 2004	Analysis of Flight Recorders.
January 29, 2004	Investigation of the MLG.
February 9–10, 2004	Investigation of maintenance work at the MLG repair facility.
March 1–6, 2004	Examination of the MLG cylinder fracture surfaces.

November 17, 2004–March 8, 2005	Fatigue strength test of the material of the MLG cylinder. [*1]

1.2.4 Progress Report

On May 27, 2005, the ARAIC submitted a progress report on the results of the factual investigation at that time to the Minister of Land, Infrastructure and Transport, and this was opened to the public.

1.2.5 Hearings from Persons relevant to the Cause of the Accident

Hearings were held to hear the opinions of persons associated with the accident.

1.2.6 Consultation with the State of the Design and Manufacture

Comments on this report were invited from the State of the Design and Manufacture.

[*1] Fatigue strength testing of the material of the MLG cylinder was conducted with the assistance of the National Institute for Materials Science (NIMS).

2. FACTUAL INFORMATION

2.1 Flight History

On January 1, 2004, a Douglas DC-9-81 owned by Japan Air System. (referred as “the company” hereinafter, currently Japan Airlines Domestic. All company names below are as at the time of the accident.), registration JA8297 (referred as “the aircraft” hereinafter), was being operated by Harlequin Air under Article 113 section 2 of the Civil Aeronautics Laws as JAS scheduled flight 979. The aircraft took off from Kagoshima at 15:35, and after cruising at FL260, began its approach to Tokunoshima Airport’s runway 01. In the cockpit, the captain assumed Pilot Flying (PF: the pilot responsible for controlling the aircraft) duties from the left seat and the first officer assumed Pilot Not Flying (PNF: the pilot responsible for duties other than control of the aircraft) duties from the right seat. Four cabin attendants (CA) were working in the cabin.

The flight plan submitted to the Kagoshima Airport Office of the Civil Aviation Bureau was as follows:

FLIGHT RULES: IFR, DEPARTURE AERODROME: Kagoshima Airport, ETD: 15:25, CRUISING SPEED: 456kt, CRUISING ALTITUDE: FL260, ROUTE: HKC (Kagoshima VORTAC) – Air Route A582 – HACHA (reporting point) – TKE (Tokunoshima VOR/DME), DESTINATION AERODROME: Tokunoshima Airport, TOTAL EET: 46 minutes, ENDURANCE: 3 hours 8 minutes, PERSONS ON BOARD: 169.

Based on recordings on the aircraft’s Digital Flight Data Recorder (DFDR) and Cockpit Voice Recorder (CVR), ATC radio communication recordings, and the statements of crewmembers and other persons, the progress of the flight from the approach to Tokunoshima Airport until the accident occurred is summarized as follows.

2.1.1 Progress of the Flight based on DFDR, CVR and ATC radio communication recordings.

At 1617:27, Kagoshima Flight Service Center (Kagoshima FSC) reported the conditions at Tokunoshima Airport as wind direction 360°, wind speed 6kt, temperature 19°C, altimeter setting (QNH) 30.09-inHg, no related air traffic at Tokunoshima Airport, and requested the aircraft to report passing high station on the VOR approach.

At 1617:51, the aircraft notified Kagoshima FSC that the crew had sighted the runway and changed to Visual Flight Rules (VFR) flight.

At 1619:36, Kagoshima FSC informed the aircraft that obstruction not reported on the Tokunoshima Airport runway, and that the wind was 360° at 7kt.

At 1621:36, the aircraft's autopilot and autothrottle were disengaged.

At 1622:04, following the checklist, the crew confirmed that the auto-brake system (ABS) was set at "MIN", and that the anti-skid system was armed.

At 1623:36, the aircraft's radio altimeter indicated 60ft, and the Engine Pressure Ratio (EPR: a measure of engine thrust) of both engines began to decrease.

At 1623:43, the radio altimeter indicated 9ft, and the fuel flows to both engines were at idle values.

At 1623:47, the radio altimeter indicated 0ft, Indicated Airspeed (IAS) was 133kt, pitch attitude was around 1° aircraft nose up, and roll angle was around 2° left. Vertical acceleration increased to 1.2G and the spoilers deployed.

At 1623:48, a smashing noise, a "LANDING GEAR" synthetic voice warning, and a "BEEE" warning sound were recorded on the CVR. The warning voice and warning sound continued to be recorded until the CVR recording stopped. At the same time, the nose gear AIR/GND sensor changed to GND. The aircraft's roll angle was around 7° left. Vertical acceleration reduced to around 0.9G, then increased to around 1.3G. The left rudder pedals moved forward and the rudder deflected to the left.

At 1623:49, the rudder pedals returned to the neutral position.

At 1623:50, the ABS activated and brake pressures began to increase.

At 1623:54–55, the depression of the left and right brake pedals increased, and the left and right brake pressures increased. After this, the left brake pedal depression gradually decreased, but the right brake pedal remained in the same position until the recordings stopped. Further, the left and right brake pressures changed corresponding to the amounts the brake pedals were depressed.

At 1623:57, the left engine's reverser deployed, at 1623:58, the right engine's reverser deployed. At around this time, the right rudder pedal moved forward and remained in a forward position until the recordings stopped.

At 1624:02–03, the reversers stowed momentarily.

At 1624:03, the co-pilot called "reverse, reverse".

At 1624:04–05, the reversers of both engines deployed again, and remained deployed until just before the aircraft came to a stop.

At 1624:14, the aircraft reported to Kagoshima FSC that it had made a single gear landing on the runway, had stopped engines, and requested runway closure.

At the time, the aircraft was rolled 10° left.

At 1624:45, Kagoshima FSC acknowledged the single gear landing, etc.

(See Figures 1 and 2)

2.1.2 Progress of the Flight based on Witness Statements

(1) The Captain

"Nothing unusual was found during the external checks at Kagoshima Airport, and there was no sign of hydraulic leakage etc. on the main landing gear. After taking off from Kagoshima Airport, we flew en-route at FL260. The weather was good, and sighting Tokunoshima Airport, I cancelled IFR and changed to VFR. I disconnected the autopilot and autothrottle before entering the downwind leg. I confirmed three greens on the landing gear. There were no warnings. As we touched down, was slowly lowering the nose, the aircraft gradually banked left, and I thought it was flat left main landing gear tire. Then I thought that the bank of the aircraft was increasing, the wing tip began to contact the runway. At the same time, the aircraft began to deviate towards the left. I applied thrust reversers just as the nose wheel was touching down. I cancelled applying thrust reversers for a moment to correct the aircraft attitude back in place, but the runway was running short, so I applied reverses again. I did not remember the first officer called "reverse". To cancel the ABS, I applied both brakes. Then I applied only right brake. Braking action was good and the aircraft stopped as I expected.

(2) The First Officer

"We cancelled IFR about 25nm from Tokunoshima Airport, and made a VFR approach. We selected the ABS to "MIN" before landing. VREF was around 129kt or 128kt. VTG was VREF +5kt, at 134kt or 133kt. Kagoshima FSC had reported a 7–8kt headwind. The touch down was a properly firm landing. After touch down, as the nose was lowering, the aircraft began to bank left. There was no shock. The wing tip was touching the ground, and as we were approaching the end of the runway, the captain was about to stow the reverse levers, but I told him "reverse, reverse", and the captain applied reversers again. The aircraft came to rest on the runway just beyond the 1,000ft from touch down markings."

(3) The Chief Cabin Attendant　　Seat position: left forward attendant seat

"The touch down was no different from usual, and I did not feel a large impact. Although a cabin attendant in charge of the aft cabin said that she heard a metallic sound like "Gashan" immediately after touch down, I did not. After that, the aircraft gradually began to bank left. I saw the left wing tip slowly touch to the ground from my seat. As I watched it, I saw white smoke coming from the wing tip. As it touched the ground I heard a metallic noise like "Shah". The aircraft continued to roll along the runway inclined to the left. During the landing roll, mixed white and black smoke appeared momentarily near the middle of the cabin and there was a burning smell, but the smell and smoke soon disappeared."

(4) A Passenger　　Seat 32D

"At the moment we touched down, I felt two bumps. The bumps were light, but as the aircraft leaned sideways I felt a floating sensation. After the aircraft had leaned, black smoke appeared in the cabin in front of the stewardess's seat to our left, and after that I smelled something like burning tires."

(5) A Fireman who conducted Firefighting and Rescue Activities

"The aircraft approached the airport from the south slightly higher than normal. There was no problem with the touch down, but immediately afterwards I saw the aircraft lean and I quickly mobilized the fire engine. I did not see smoke. We followed the aircraft in two fire engines. Soon after we entered the runway, we saw various parts scattered around, and realized this was an accident. We saw oil, fuel or something spilled under the aircraft's wheels, and so we sprayed foam at the site. There was no outbreak of fire, but we waited by the aircraft. By chance, we had done firefighting training at the airport in December, and I think we responded quickly because of that."

(6) A Company Employee contracted by Harlequin Air to support Ground Duties. ("Ground Staff")

"I heard the aircraft landing, and as I was thinking it had arrived I heard a sound like "Gashan" and saw white smoke. It crossed my mind to call fire engines and ambulances, but the fire engines were already rolling. I called for ambulances from the office. We took walkie-talkies and approached the aircraft by ground cart. When we arrived at the scene, foam had already been sprayed around the left wing tip. I was relieved that there was no fire. Some passengers were already disembarking. There was a light wind from the north so we directed the passengers to move north of the runway as far away from the aircraft as possible.

"I confirmed the state of injuries with the cabin attendants, and there were no injuries at that time. After that, buses soon arrived and picked up the passengers."

The accident site was on the runway around 1,750m from the approach end of runway 01 at Tokunoshima Airport. The accident occurred at around 16:24.

2.2 Deaths, Missing Persons and Injuries

Three passengers were slightly injured.

2.3 Damage to the Aircraft

2.3.1 Extent of Damage

Substantial damage

2.3.2 Damage to the Aircraft by Part

(1) Fuselage

Trapezoidal panel [*2]	Damaged
Fillet between wing and fuselage	Damaged

(2) Left wing

Front spar	Deformed
Leading edge slat, Flap, Lower skin, and Wing tip	Damaged

(3) Left main gear and surrounding area

Shock strut cylinder	Broken into two pieces
Retract actuator, side brace	Deformed
Main wheel well inboard door	Damaged
(4) Left engine fan blades	Damaged
(5) Tail cone	Damaged

(See Photographs 1, 2, 3, 4, 5, 6, and 7)

2.4 Damage to Other than the Aircraft

Six runway edge lights were damaged.

2.5 Crew Information

2.5.1 Flight Crew

(1) Captain: Male, aged 62

Airline Transport Pilot Certificate (airplane)	Issued August 11, 1971
Type Ratings	
Douglas DC-9	Issued April 12, 1979
Class 1 Airman Medical Certificate	
Term of Validity	Until May 22, 2004
Total flight time	20,497 hours 38 minutes
Flight time during the previous 30 days	55 hours 39 minutes
Total flight time on Douglas DC-9	12,832 hours 54 minutes
Flight time during the previous 30 days	55 hours 39 minutes

(2) First Officer: Male, aged 36

Commercial Pilot Certificate (airplane)	Issued February 19, 1990
Type Rating	
Douglas DC-9	Issued April 28, 1998
Instrument rating	Issued August 2, 1993
Class 1 Airman Medical Certificate	

[*2] The trapezoidal panel is a major structural component located at the wing-body join area.

Term of Validity	Until September 6, 2004
Total flight time	5,533 hours 52 minutes
Flight time during the previous 30 days	51 hours 08 minutes
Total flight time on Douglas DC-9	3,403 hours 25 minutes
Flight time during the previous 30 days	51 hours 08 minutes

2.5.2 Cabin Attendants

(1) Chief Cabin Attendant Female, aged 41 Seat position: Forward left
Total service flight hours 1,759 hours

(2) CA 1 Female, aged 25 Seat position: Forward right
Total service flight hours 1,993 hours

(3) CA 2 Female, aged 32 Seat position: Aft left
Total service flight hours 2,182 hours

(4) CA 3 Female, aged 31 Seat position: Mid
Total service flight hours 2,855 hours

2.6 Aircraft Information

2.6.1 Aircraft

Type	Douglas DC-9-81
Serial Number	49908
Date of Manufacture	August 9, 1990
Certificate of Airworthiness	Tou-10-700
Term of validity	From December 8, 1998, provided JCAB approved maintenance manual (for Japan Air System) applies
Aircraft Category	Airplane Transport
Total flight time	26,050 hours 48 minutes
Flight time since scheduled maintenance “C” Check on October 8, 2002	2,573 hours 07 minutes

2.6.2 Engines

Type: Pratt & Whitney Model JT8D-217C

Position	Serial No.	Date of manufacture	Total time in service
No.1	P728022D	February 4, 1994	14,717 hours 03 minutes
No.2	P725875D	May 11, 1991	21,061 hours 10 minutes

2.6.3 Main Landing Gear Shock Strut Cylinders

Position	Left	Right
Part Number	5935348-7	5935348-7
Serial Number	CPT1489	CPT1335
Total Cycle of Landing (TCL)	26,176 cycles	26,525 cycles
TCL after Overhaul	7,834 cycles	7,834 cycles

2.6.4 Weight and Center of Gravity

The aircraft's weight at the time of the accident was estimated as approximately 121,995lbs, with the center of gravity at 12.4% MAC, both values being within the allowable limits (maximum landing weight 128,000lbs, with an allowable center of gravity range corresponding to the weight at the time of the accident of -0.8–32.1% MAC).

2.6.5 Fuel and Lubricating Oil

The fuel on board was JET A-1. The lubricating oil was Mobil 254.

2.7 Meteorological Information

The aeronautical meteorological observations by Tokunoshima Airport Office during the time period relating to the accident were as follows:

Time of Observation	16:00 JST	16:42 JST
Wind Direction	340 degrees	010 degrees
Wind Velocity	8kt	5kt
Visibility	25 km	20 km
Cloud amount	1/8	1/8
Cloud type	Cumulus	Cumulus
Height of cloud base	4,500 ft	4,000 ft
Cloud amount	---	3/8
Cloud type	---	Stratocumulus
Height of cloud base	---	5,000 ft
Temperature	19°C	18°C
Dew point	8°C	8°C
Altimeter Setting (QNH)	30.09-inHg	30.09-inHg

2.8 Aeronautical Navigation Aids

No anomalies were found with aeronautical radio navigation aids at the time of the accident.

2.9 Communication Information

Radio communications between the aircraft and Kagoshima FSC at the time the accident occurred were satisfactory.

2.10 Aerodrome Information

Tokunoshima Airport is located by the shore on the west coast of Tokunoshima Island, and its field elevation is 8ft. The single runway 01/19 is 2,000m long and 45m wide, and there is a 60m long overrun zone at each end. The runway is paved with asphalt concrete, and is grooved over a length of 2,000m and a width of 30m.

2.11 Flight Data Recorder and Cockpit Voice Recorder

2.11.1 DFDR

The aircraft was equipped with a Honeywell DFDR (part number 980-4100-DXUS), and the recorded data at the time of the accident remained in the recorder.

Since VHF transmission keying data were recorded by the DFDR, the DFDR time was corrected to Japan Standard Time by correlating the VHF transmission keying data with the NTT time signal and radio communications on ATC communication recordings.

2.11.2 CVR

The aircraft was equipped with a Honeywell CVR (part number 980-6005-076), and sounds and voices at the time of the accident remained on the recorder.

The CVR time was corrected to Japan Standard Time by correlating the communications on the CVR with the NTT time signal and radio communications on ATC communication recordings.

2.12 Accident Site and Wreckage

2.12.1 Accident Site

The site of the accident was on the runway at Tokunoshima Airport. The aircraft came to rest around 1,750m from the threshold of runway 01. Traces of the left wheel tires of the left MLG were found on the runway around 570m from the threshold of the runway 01, and appeared as if they had been twisted to the right. One hundred meters further along, traces of the nose wheel tires and of left wing tip contact with the runway were found, and traces of the wing tip continued to the point at which the aircraft came to rest.

Hydraulic fluid was found on the runway in the vicinity of where the aircraft came to rest.

(See Figures 1 and 2)

2.12.2 Aircraft Damage

The left MLG shock strut cylinder was broken into two pieces by a circumferential fracture approximately 21 inches from its top end (approximately 30 inches from the bottom end). The lower portion of the cylinder did not separate from the aircraft but was retained by the retraction actuator and side brace, and was pulled along by them.

(See Photographs 3 and 6)

Due to the lower portion of the cylinder being dragged along, the side brace was pulled aft-wards, and the trapezoidal panel structural component was damaged. Further, the left wing flap and the fillet between the wing and fuselage were damaged.

(See Photographs 3 and 5)

Because the left wing tip traveled in contact with the runway, parts of the left navigation light, wing lower skin panels, access panels, slat leading edge, flap trailing edge, flap track fairings, main wheel well inboard door etc. were damaged. Part of the front spar was deformed into a convex shape over an approximately 85cm area, with a maximum deformation of 9mm at a point 3m inboard from the wing tip.

(See Photographs 3 and 4)

Due to deployment of the evacuation slide at the most aft emergency exit, the tail cone fell from the aircraft and was damaged.

Dents and nicks were found in the leading edges of several fan blades of the left engine.

(See Photographs 2, 3 and 7)

2.13 Medical Information

Based on the statements of the injured persons described in section 2.2, the state and extent of injuries sustained were as follows. All passengers had their seatbelts fastened when the aircraft landed.

(1) Seat 1B Male aged 21

Diagnosed with bruising of the lower back on the day of the accident, which took 5 days to heal.

(2) Seat 15B Female aged 59

Diagnosed with cervical sprain five days after the accident, which took two weeks to heal.

(3) Seat 27A Female aged 22

Diagnosed with spondylosis from neck and shoulder symptoms on the day after the accident, which took seven days to heal.

2.14 Fire and Firefighting Activities

The following is a summary regarding outbreak of fire and firefighting activities based on the statements of staff of the Tokunoshima Airport Office (the Airport Office), firemen and other related airport staff.

At 16:24, firemen at the airport who witnessed the abnormal situation on the aircraft's landing followed the aircraft in two fire engines. There was no outbreak of fire, but as a precaution chemical foam was sprayed on the left of the fuselage by a large foam fire truck.

At 16:25, the Airport Office made an emergency 119 telephone call reporting the accident to the Tokunoshima Area Fire Fighting Union Office, which then mobilized the Amagi Branch Office (the Fire Union). The Airport Office notified Kagoshima FSC of the accident and reported that there was no outbreak of fire.

At 16:27, the Fire Union dispatched a fire engine. Kagoshima FSC issued a runway closure NOTAM.

At 16:34, the Fire Union fire engine arrived at the accident site.

At 16:37, the Fire Union fire engine returned. The Airport fire engines remained on watch near the aircraft.

2.15 Information on Search, Rescue and Evacuation relevant to Survival, Death or Injury

2.15.1 Rescue and Evacuation

Based on statements of the Airport Office staff, firemen, and other airport staff, rescue and evacuation activities were carried out as follows.

At 16:24, two staffs at the Airport Office who were watching the aircraft land heard an abnormal sound at touch down, and immediately rushed by car to the place where the aircraft had come to rest. Escape slides were deployed immediately after the aircraft stopped, but passengers began to disembark by the forward air stairs. Passengers who were unable to disembark by themselves were assisted from the aircraft by the captain and firemen. Disembarked passengers were guided away from the aircraft by the first officer, the Airport Office staff, and other airport staff, and evacuated to the upwind side of the aircraft.

At 16:27, an ambulance was dispatched from the Fire Union.

At 16:29, an accident task force was established at the Airport Office, and information began to be distributed to each associated station in accordance with emergency information handling procedures.

At 16:34, the Fire Union ambulance arrived at the accident site. Of the disembarked passengers, one male described in section 2.13 and an uninjured pregnant woman were transferred to hospital on the advice of a doctor.

At 17:28, the Fire Union ambulance arrived at the hospital and the two persons transferred were handed over to hospital medical staff.

2.15.2 Passenger Evacuation Guidance by the Crew

According to the statements of the flight crew, cabin attendants, Airport Office staff, firemen, and other airport staff, the evacuation of passengers was directed as follows.

Immediately after the aircraft came to rest, the captain shut down the engines and at the same time switched on the emergency lights. At the time the aircraft stopped, the first officer reported to Kagoshima FSC and requested closure of the runway. The first officer confirmed that there was no fire in the cabin and reported this to the captain, and then announced to the passengers using a megaphone 'we have made a single-gear landing and the wing tip has touched the ground. There is no fire. Please follow instructions'. The captain ordered the cabin attendants to deploy the escape slides after the aircraft stopped as a precaution. Because the fuselage was inclined to the left, the forward right slide was at a dangerous height above the ground and so was not deployed. However, because there was no outbreak of fire, the captain made all passengers disembark using the forward air stair without using the slides. The captain and cabin attendants directed passengers to evacuate by PA in the cabin, and the first officer outside on the ground directed the passenger evacuation.

Airport Office staff and airport staff who had witnessed the accident arrived at the accident site shortly after the accident and guided the passengers.

2.15.3 Harlequin Air Emergency Evacuation Procedures

2.15.3.1 Emergency evacuation is described in the OPERATIONS MANUAL (OM) as follows. (Extract)

Generally, the following situations are thought to possibly require an emergency evacuation.

(1) If there is a fire on board the aircraft.

(2) If the cabin is filled with smoke.

(3) If there is an abnormal inclination of the fuselage on take-off or landing.

(4) If abnormal sounds or impacts are felt.

(5) If a leakage of fuel etc. is recognized.

2.15.3.2 Section 2-3-3 of the AIRPLANE OPERATING MANUAL (AOM), Emergency Landing(Ditching), describes the duties and divisions of responsibility during emergency evacuation as follows. (Extract)

1. Standard crew duties

PIC [Pilot In Command]

(1) When an evacuation is judged to be necessary, order the crew and passengers to begin evacuation at the earliest opportunity.

(2) After completing cockpit duties, leave the cockpit and direct the evacuation from the best place to be able to do so. If necessary, go to the aft cabin and assist the cabin attendants in helping passengers in that area to evacuate the aircraft in the best way, then leave the aircraft. If unable to enter the cabin, escape from the aircraft after completing cockpit duties and assist the passenger evacuation from outside.

Note 2: When it is necessary to prevent an unintended evacuation, repeat announcements such as "This is the captain, please remain seated" to the cabin attendants and passengers using the PA.

First officer

(1) After completing cockpit duties, if necessary go to the forward cabin, direct the evacuation of passengers in that area with cabin attendants, and assist passengers to evacuate in the best way, and then leave the aircraft. If unable to enter the cabin, escape from the aircraft after completing cockpit duties and assist the passenger evacuation from outside.

(2) When it is necessary to assist from outside the aircraft as ordered by the PIC, leave the aircraft quickly and assist the passenger evacuation from outside the aircraft. Direct the passengers who have left the aircraft to evacuate to a safe area.

Cabin attendants

(1) On the direction of the PIC, open the escape exit for which you are responsible and evacuate the passengers. Permit others to assist in opening escape exits as necessary.

(2) Assist passengers to evacuate in the best way, and then leave the aircraft.

(3) Direct passengers who have left the aircraft to evacuate to a safe area.

2. Division of Responsibility for Escape Exits

Regarding the use of all escape exits for which crew are responsible, if it is judged that an escape exit cannot be used or that escaping from that exit would be dangerous, guide passengers to another escape exit, and assist passengers in evacuating.

2.16 Tests and Research to Find Facts

2.16.1 Examination of the Main Landing Gear Cylinder by the Aircraft Manufacturer

To investigate the cause of the fracture of the aircraft's left MLG cylinder, the cylinder was sent to a laboratory of the aircraft's manufacturer and was examined by metallurgical analysis etc. The examination was witnessed by two ARAIC investigators, a US National Transportation Safety Board (NTSB) investigator, and a US Federal Aviation Administration (FAA) inspector.

The results of the examination were as follows.

(1) Visual inspection.

The MLG cylinder was fractured at the fuse section [*3]around 21 inches below the top the cylinder. Fatigue origins were found more than five locations on the fracture surface.

(See Photographs 8 and 9)

(2) Examination of Fracture Surface

Large five fatigue origins within the fatigue origins mentioned above were found along a circumferential length of 2.35 inches. Of these, three largest fatigue origins which were the origins of the collapse fracture were located along a circumferential length of around 0.88 inches. The largest of these three fatigue origins is referred to as Origin 1 in the following discussion. (See Photograph 9)

The Origin 1 was around 0.205 inches in width, and the total crack length of the five locations was around 0.61 inches. The depth of the Origin 1 was reached 0.085 inches from the cylinder surface, and it was deepest fatigue trace than other traces.

Slight damages were found on the cylinder surface around Origin 1. When the cadmium plating on the cylinder surface was removed, traces of grit blast[*4]treatment were found on the cylinder surface, but no evidence of damage was observed.

(3) Scanning Electron Microscope (SEM) Analysis of the Fracture Surface

As a result of SEM inspection of the Origin 1, fatigue striations were found that showed a fatigue crack propagated within a depth of 0.050 inches of the cylinder surface, but no evidence of dimple[*5]rupture was found in this depth range.

Between depths of 0.050–0.085 inches, the propagation of a crack had resulted in the cylinder material becoming more susceptible to cracking, and the primary crack front displayed increasingly wide bands of dimple rupture only, indicating momentary periods of crack instability.

Beyond depths of 0.085 inches, the remaining rapid fracture displayed a predominant dimple mode of rupture. (See Photograph 10)

(4) Composition Analysis of the Fracture Surface

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*3 The fuse section is a section of the gear strut of reduced wall thickness specific portion of the cylinder which is designed to break before wing structure break to prevent wing fuel tank rupture, and the subsequent fuel spillage and risk of fire, that might occur due to collapse of the wing structure under excessive loads transmitted through the landing gear if an aircraft overruns over a rough surface.

*4 Grit-blast is performed before plating parts that have been newly manufactured or overhauled. By blasting minute grains of aluminum oxide onto the metal surface to be plated, foreign matter adhering to the surface such as rust etc. are removed and the surface is roughened, improving adhesion of the plating.
There are few examples of specifications that require grit-blast before plating, but because it is an effective pre-plating treatment, it is usually performed before plating whether required by specifications or not.
There is no official standard related to grit-blast, but in general it is carried out according to the aircraft manufacturer's specifications.

*5 Dimples are many minute depressions created on a fracture surface when metal ruptures rapidly.

Energy Dispersive Spectrometry analysis of the surface at Origin 1 showed that along with the alloy elements of the base metal, and O (oxygen), Si (silicon), P (phosphorus), Ca (calcium) with residual elements of post fracture corrosion and remnants of paint stripping were detected. Cd (cadmium), which is used in the plating on the cylinder surface, was also detected.

(5) Microstructure Examination

Microstructure examination of the fatigue fracture origin areas found no evidence of abnormality.

(6) Dimensional Inspection

That outer diameter, inner diameter, depth, etc. of the cylinder were measured, and the dimensions were found to be within specified tolerances.

(7) Hardness Test

A general hardness test of the cylinder material and a micro hardness test of a very shallow zone around the cylinder surface were conducted, and the hardness was found to be within specified tolerances.

A layer of surface hardening caused by shot peening[*6] of the cylinder surface could not be confirmed; however the manufacturer stated that the hardness tests are unable to detect a hardened surface layer.

(8) Chemical Analysis

Chemical analysis of the cylinder material found that its composition was as specified.

(9) Tensile Strength Test

A tensile strength test conducted at room temperature showed that tensile strength, yield strength, elongation, etc. were all within specified tolerances.

(See Figure 4)

2.16.2 Additional Investigation of the Main Landing Gear Cylinder

The additional investigation of the fractured cylinder was carried out with the assistance of the "NIMS" that the trace of fatigue origins was observed on the ruptured surface of the cylinder. The result of the additional investigation as follows.

(1) Examination of Fracture Surface

As described in section 2.16.1, five large fatigue origins were found at the fracture surface in a 2.53-inch area. However, the additional investigation found cracks with a

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*6 Shot peening is a cold work hardening method in which steel balls, etc. of around 0.5mm in diameter are blasted onto the surface of a metallic material. This creates plastic deformation and compressive forces in the surface of the material. This shot peening creates the layer of residual compressive stress in the surface of the material, enhance resistance to stress corrosion cracking and increases its fatigue resistance. However, the layer of residual compressive stress generated by the shot peening may be relaxed when the material received strong stress.

length along the outer contour greater than 1 mm at seven locations. This discrepancy arose because the manufacturer counted each instance where two fatigue origins overlapped as one location.

All the fatigue origins originated at the surface of the cylinder, but there was no foreign materials around the origin.

(2) Examination of the Cylinder Material Structure

A test specimen was removed from near the cylinder fracture surface, and after polishing the cut surface, its structure was found to be regular.

(3) Hardness test of the cylinder material

Using the test specimen from (2) above, a hardness test was conducted near the fracture surface at a position around 10mm away from the fracture surface. The hardness was found to be within the manufacturer's specifications. Further, an depth of hardened surface layer by shot peening was approximately 0.2mm by micro hardness test.

(4) Examination of cylinder surface and cross-section

As a result of the observation around the fractured cylinder surface after Ni-Cd plating was stripped, roughness and flaw were found on the surface. Also, there were similar flaw on the surface of the lower part of the cylinder as described in (5) below although the number of flaw is small compared with the area around the fractured surface.

Apart from the above roughness and flaw, other portion of the cylinder than the fractured surface was cut longitudinally and the cut surface was polished, and the material near the surface was examined. The examination found roughness of the surface and grains of aluminum oxide used in grit-blast were found embedded in the surface. Also, plastic deformation (plastic flow) features were found where the grit of aluminum oxide embedded on the surface.

(See Photographs 11 and 12)

(5) Fatigue strength test of the cylinder material

Refer to the above (4), the cylinder fatigue strength tests were carried out because roughness and surface flaw were found on the cylinder surface, to check the influence of roughness and surface flaw on the fatigue strength of the cylinder. To make the comparison of fatigue strength, between the surface material that was cut from the lower part of the cylinder having roughness and surface flaw, and the material of the inside that was not affected by shot peening or grit-blast each 8 specimen respectively were prepared and fatigue strength tests using these specimen were carried out. Fatigue strength tests were conducted by loading specimens with a cyclical constant-amplitude axial load.

1) Test using the material of the inside

Fatigue strength tests were carried out at 650MPa, 700MPa, 750MPa, 800MPa and 850MPa stress amplitude[*7]. The results were as follows.

a. Fatigue collapse were all internal fractures[*8]. The fracture origins were at nonmetallic inclusions (here after mentioned as "inclusions") in the material.

b. The inclusions were of titanium nitride, aluminum oxide, sulfurize manganese, etc. all incorporated during refining of the raw material, and all quantities were within normal ranges.

c. The fatigue strength was found to be sound.

2) Test using the surface material

Fatigue strength tests were carried out at 550MPa, 600MPa, 650MPa, 700MPa, 750MPa, 800MPa and 850MPa stress amplitude. The results were as follows.

a. At greater than 650MPa stress amplitude, the specimen collapsed from the surface. The origin of the fracture was surface flaw.

b. At less than 600MPa stress amplitude, the specimen collapsed from within. The origin of the fracture was attributed to the inclusions described in 1) above.

c. The fatigue strength of the specimen lower in comparison with the test specimen of 1).

(6) Load to rupture

Stress concentrates at the tip of a fatigue crack, and consequently in some cases a structure may be ruptured by considerably lower stresses than the yield stress or tensile strength of the material. In other words, when the stress intensity factor (K) which used as an index which represents the magnitude of stress concentration is reached to the fracture toughness (K_{IC}) value, the rupture will generate. When in the case of fatigue fracture, area of fracture surface which generated by fatigue and the maximum stress intensity factor (Kmax) which leads from the maximum load acting on the material, is reached to the fracture toughness (K_{IC}), it generates rapid fracture

The relation between the area of fracture surface and Kmax can be expressed by the following formula (the formula of Murakami).

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*7 The stress amplitude is half the value of the difference between the maximum and minimum of repetitive loading stresses. Therefore, in the case of loading is one side stress tests and when the minimum stress is zero, the maximum stress at this time is twice the stress amplitude.

*8 Internal Fracture means the origin of the internal fracture start from the inclusion which can not avoid as steel material and come inside fatigue fracture phenomenon and called "Fish - Eye Fracture".

$$K_{max} = 0.65\,\sigma_{max}\sqrt{\pi\sqrt{A}}$$

A: the area of fracture surface

According to the investigation report of a similar accident involving DC-9 in Britain, the fracture toughness (KIC) value of cylinder material(300M) is 60 ksi√in. The report also describes that the measured value of KIC is 68.2 MPa√m (63.01 ksi√in). As a result of the examination carried out by NIMS it is found that the value of KIC is 54.6 to 74.9 MPa√m for the internal material, and 62.6 to 74.8 MPa√m for the surface material. The value of KIC from the NIMS examination is almost the same as that in the report of Britain. From the above it is found that the cylinder material was sound

To use KIC which got from the fatigue test of each specimen and the most wide area of fatigue fractured surface of the cylinder(origin 1), calculated the stress when the cylinder rapidly fractured. As a result, the stress of final fracture was at least 1,200MPa.

2.16. 3 Attitude and Vertical Acceleration on Landing based on DFDR data

Based on the DFDR recordings, at touch down IAS was around 133kt and roll angle was around 2° left, and roll angle attained 7° left one second after touch down. Pitch angle was around 1° nose up at touch down, and two seconds after touch down the aircraft was at an attitude of 0°. Just before touch down, the rate of descent below 10ft above the ground was around 2 ft/s (around 0.6m/s). The vertical acceleration acting on the aircraft was around 1.2G at touch down and then decreased slightly, and around one second after touch down a value of 1.3G was again recorded. The radio altimeter was indicating 0 ft at touch down, and minus 2 ft one second after touch down. Brake pressure just before touch down and for three seconds after touch down was of the same degree as in flight (19.6–57psi).

2.17 Other Information

2.17.1 Main Landing Gear

The main landing gear of the Douglas DC-9-81 absorbs the shock of landing and vibrations during ground maneuvering by an orifice in the main landing gear cylinder, an oleo pneumatic piston and hydraulic fluid. Shimmy of the MLG is dampened by a shimmy damper installed on a torque link. The cylinder, into which a piston connected to the axle is inserted, is forged from 300M high-tension steel as specified by the manufacturer.

After forging, manufacture of the cylinder is completed by the following processes.

(1) Heat treatment

(2) Machining

(3) Shot peening

(4) Grit-blast

(5) Cadmium plating

(6) Painting

According to information from the manufacturer, the cylinder's fuse section is treated by shot peening to the same specification as other parts of the cylinder.

2.17.2 Brake System

The aircraft was equipped with a brake system in which braking is performed by hydraulically actuated pistons pressing linings against a steel disc. The brake system can be operated manually by the pilot stepping on brake pedals, and by an auto-brake system which operates automatically without pilot action.

The brake system is equipped with an anti-skid system. When the system's anti-skid control unit senses an incipient skid by signals from speed sensors installed on each of the main wheels, it controls the corresponding anti-skid control valve to adjust brake pressure to obtain maximum braking effect without skidding. Both left and right hydraulic systems are connected to left and right brakes, so that both left and right brakes are able to function if an only single hydraulic system is operative. The anti-skid system also has touch down protection function to prevent tire burst on landing if the pilot steps on the brake pedals before touch down by inhibiting braking for about three seconds from the time the AIR/GRD sensor on the nose gear changes to "GRD" mode, or until a spin up (wheels starting to turn) signal is issued by the speed sensors on the main wheels.

The Hydraulic Fluid Quantity Limiter is installed on each hydraulic line connected to the brakes. In the event of damage downstream of the device causing a large loss hydraulic fluid, the limiter closes to prevent further loss of hydraulic fluid.

2.17.3 Landing Gear Warning System

The landing gear warning system on the aircraft issues a voice warning "Landing gear" and sounds a "BEEE" warning sound in the following circumstances.

(1) If the landing gear is not locked down when IAS reduces to below 210kt with the thrust levers in the idle position. In this case, when the voice warning and warning horn are sounding, they can be silenced by pushing a "Gear Horn OFF" button.

(2) If the landing gear is not locked down when the flaps are set to 26° or greater. In this case, pushing the "Gear Horn OFF" button does not silence the alerts, but the warning voice and horn stop when the landing gear is extended and locked down.

2.17.4 Gear Walk

Gear walk is a phenomenon that the main landing gear moves fore and aft during braking while the aircraft is traveling on the ground.

When the brakes are operated while the aircraft is traveling on the ground, the main landing gear strut experiences an aft bending force due to the friction between the tires and the runway surface, and looking from the aircraft, the wheels move aft and finally skidding occurs. When a skidding occurs between tires and runway surface, the brake system senses skid with anti-skid system and relieves brake pressure to cancel skid condition. When brake pressure is relieved, the aft bending load acting on the main landing gear strut is released and the wheels return to their original positions. Then, when brake pressure increases again, the aft bending force acts on the main landing gear strut again and the wheels move aft. If the natural frequency of the fore and aft bending of landing gear strut coincides with the "ON and OFF" cycles under such braking conditions, the fore and aft movements of the main gear may be increased. Furthermore, it is more likely to occur to the aircraft equipped with the anti-skid valve called the "high gain valve" which opens and closes the valves many times in one second.

Gear walk has been observed on the Douglas DC-9 series when the brakes are applied "moderate to strong" while the aircraft is traveling about 40 – 60 kt. The frequency of fore and aft movement under such conditions has been measured at 12 cycle/sec. during rolling tests by the manufacturer using an actual aircraft, and the fuse section on the cylinder is loaded with a worst-case stress of 270ksi due to Gear Walk.

To prevent Gear Walk, the manufacturer issued a service bulletin (SB) [*9] to install a restrictor[*10] in the brake hydraulic lines.

2.17.5 History of Left Main Gear

The left MLG which collapsed in the accident was installed on JA8295, another aircraft belonging to the Company of the same type as the accident aircraft, at the time of the aircraft's manufacture in August 1989. The left MLG was removed from JA8295 in July 1999, overhauled at a repair station, and then reinstalled on the accident aircraft in April 2000 after the overhaul was completed. An outline of the history of the left MLG is as follows.

In August 1989, severe brake vibration occurred during a rejected take-off (RTO) ground test carried out by the manufacturer before the aircraft delivered to the company, then brake system was carried out air-bleed. Severe brake vibration occurred again during an RTO test on the 3rd flight test, and the Anti-Skid control box and other parts were replaced.

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*9 An SB, short for "Service Bulletin", is technical information issued by the manufacturers of aircraft and components for the purposes of increasing safety, improving performance, disseminating information, etc.

*10 A restrictor is a valve which installed in brake hydraulic circuit that restricts the flow in the line feeding hydraulic fluid to the brakes, but does not restrict fluid returning from the brakes. The restrictor alters the pressure response of the brake when the antiskid system increases and decreases the applied brake pressure. The altered brake pressure responses reduce dynamic motion of the landing gear.

Severe brake vibration again occurred during an RTO test on the 4th flight test, and all brakes and the Anti-Skid control box, etc. were replaced.

In April 1992, a restrictor was installed in the brake hydraulic lines of JA8295 in accordance with the manufacturer's SB (MD-80-32-246).

In February 1995, the special inspection was carried out with the captain's report of a suspected hard landing, and no abnormality was found.

In December 1995, the fuse section was inspected for cracks in accordance with the Japanese Airworthiness Directive (TCD:[*11]) TCD-4322-95 (conforming to SB80-32A286). No cracks were found.

In July 1999, the MLG was removed from the aircraft because it was approaching its overhaul time.

In March 2000, the MLG was overhauled at a repair station. At the time, the crack inspection of the fuse section in accordance with TCD-4322-95 (conforming to SB80-32A286 Rev.3) was carried out by the company order. (No cracks were found.)

In April 2000, the MLG was installed on the aircraft as the left MLG.

In October 2000, the fuse section was inspected for cracks in accordance with TCD-4322-95 (conforming to SB80-32A286). No cracks were found.

In January 2004, the MLG collapsed. At the time of collapse, the total number of landings was 26,176 cycles, the number of landings after overhaul was 7,834 cycles, and the number of landings after installation of the restrictor was 21,248 cycles.

2.17.6 Cracks on MLG Cylinders of other Aircraft

After the collapse of the aircraft's left MLG, the Company carried out non-destructive inspection (NDI: Fluorescent Penetrant Inspection and Magnetic Particle Inspection) on the MLG cylinders of all its DC-9 series aircraft from January 1, 2004. As a result, cracks were detected on the right MLG (Serial Number: CPT1292) of JA8496, the same type of aircraft as the accident aircraft.

The MLG on which cracks were found had been installed on JA8295, mentioned in section 2.17.5, at time of that aircraft's manufacture. This MLG had been used as a pair with the collapsed cylinder (Serial Number: CPT1489) from its installation until its removal from JA8295 for overhaul. The service history of the cracked MLG is summarized below.

[*11] TCD is the directive by which the Civil Aviation Bureau of the Ministry of Land, Infrastructure and Transport orders aircraft operators etc. to carry out an inspection, modification, etc. to ensure safety and a compliant environment. ADs are issued by the US Federal Aviation Administration (FAA) for the same purpose.

In February 2000, the MLG was overhauled at a repair station. During the overhaul, the Company ordered that the fuse section be inspected for cracks in accordance with TCD-4322A-99 (conforming to SB80-32A286 Rev.3). No cracks were found.

In March 2000, the MLG was installed in the right position on JA8496.

In October 2000, the fuse section was inspected for cracks in accordance with TCD-4322A-99 (conforming to SB80-32A286 Rev.3), and no cracks were found.

In January 2004, a special inspection after the accident to the aircraft found cracks on the cylinder.

The total number of landings at the time the cracks were found was 25,933 cycles, the number of landings after overhaul was 7,591 cycles, and the number of landings after installation of the restrictor was 21,005 cycles.

2.17.7 The Company's Main Landing Gear Cylinder Inspections

Detailed inspection of the MLG cylinder was carried out only during overhaul, but general external visual inspection of the MLG was conducting during line maintenance, periodic maintenance, etc.

Other than general external visual inspection, a special NDI was carried out based on the manufacturer's SB and the TCD issued by JCAB as described in section 2.17.11. This NDI was conducted by a Level 2 qualified inspector based on NAS specification 410 [*12].

The Company's maintenance manual for the aircraft prescribed that MLG overhauls should be carried out after 20,000 landings or 10 years in service, whichever occurs first.

2.17.8 Main Landing Gear Overhaul Work

The left and right main landing gears which were installed on JA8295 at the time of its manufacture were removed on July 28, 1999 as they were approaching their overhaul time. At the time of their removal they had accumulated around 18,000 landings and 10 years in service. The overhaul was conducted at a repair station. The right MLG was overhauled between August 10, 1999 and February 23, 2000, and the left MLG was overhauled between August 10, 1999 and March 20, 2000.

The result of an investigation into the overhaul work practices of the repair station is summarized as follows.

[*12] NAS 410 specification is U.S. Aviation Standard Specification which prescribes the requirements and the test methods, etc. for inspectors involved in NDI. An inspector qualified at Level 2 can adjust and calibrate test equipment, carry out and supervise inspections, and judge test results.

(1) The repair station carried out overhaul work in accordance with an overhaul procedures manual named “Repair Standard”. This had been compiled in accordance with the manufacturer’s Component Maintenance Manual: CMM.

(2) The TCD work (NDI based on the manufacturer’s service bulletin SB80-32A286 Rev.3) was carried out in conjunction with overhaul work while the cylinder plating was removed. The NDI inspection for cracks was carried out by a qualified inspector (Level 2 qualified inspector based on NAS 410 specification) using calibrated facilities and equipment in accordance with the specified standard. The inspection found no cracks.

(3) After NDI, the cylinder was re-plated (titanium-cadmium plating). Since the titanium-cadmium plating was not approved by the manufacturer, the repair station established the specified standard using the titanium-cadmium plating (Equivalent to BAC5804) and Japan Civil Aviation Bureau approved the specified standard. The plating work was carried out in accordance with the specified standard (Equivalent to BAC5804) using calibrated facilities and equipment by a mechanic whose qualifications were recognized by the repair station.

Prior to plating, the cylinder surface had been cleaned by grit-blast which meet the standards by the specified standard mentioned above.

Investigation of the work areas, facilities, equipment, inspection areas, etc., found no anomalies.

2.17.9 Grit-Blast Specifications prior to Plating

(1) Grit-blast Specification by the manufacturer.

At manufactured(As specified inDPS 9.28 for cadmium plating, which includes Surface Protection Instructions);

Blast material: Aluminum oxide grain

Blast material size: 100 - 180 mesh

Blast pressure: air pressure, not specified

At repaired (As specified in DC-9 Overhaul Manual OHM 20-10-6 Figure 6 for dry abrasive cad plating with unbrightend cyanide process) ;

Blast material: Aluminum oxide grain

Blast material size: 100 - 180mesh

Blast pressure: air pressure, 20 - 50psi (around 1.4～3.5kgf/cm^2)[*13]

(2) Grit-blast specification at the repair station

Blast material: Aluminum oxide grain

Blast material size: 100 - 180 meshes

[*13] This blast pressure is called for the manufacturer specification if a 3/8 to 1/2 inches venture-type nozzle is used. (This footnote is added with reference to the comment of the U.S. Accredited Representative.)

Blast pressure: air pressure, 5kgf/cm^2 or less

(3) Grit-blast specification at the other repair station of large aircraft landing gears in Japan

Blast material: Aluminum oxide grain

Blast material size: 100 meshes

Blast pressure: air pressure, 1.5kgf/cm^2

2.17.10 Crack detection Inspection Methods and Limits

For crack inspection of MLG cylinders, the manufacturer recommends to first carry out a fluorescent penetrant inspection followed by magnetic particle inspection. Crack inspection is conducted by two methods in order to increase the probability of detecting cracks.

Fluorescent penetrant inspection is a crack detection method in which a penetrating fluorescent fluid is applied to defects and illuminated by ultraviolet light, and is effective in detecting some defects on the surface of a material.

Magnetic particle inspection is effective method in detecting defects on and immediately below the surface of a material. If a material with defect on or immediately below its surface is magnetized, some flux leakage occurs at the defect and a magnetic pole is created. When a fluorescent magnetic powder is sprayed onto the material, the powder is absorbed and forms a pattern. The particles are illuminated by ultraviolet ray and a crack can be detected visually by the pattern of magnetic powder.

The reason for carrying out fluorescent penetrant inspection first is that if a magnetic particle inspection is carried out first and the magnetic powder penetrates a crack, fluorescent penetrant fluid will not then be able to penetrate the same crack.

According to the manufacturer, while the length of cracks that can be detected varies according to the crack depth and the conditions under which the tests are carried out, these methods are able to detect cracks with a minimum length of around 0.0625 inches (1.6mm).

2.17.11 Similar Past Accidents and the Manufacturer's Responses

Since 1995, similar accidents to the aircraft's MLG collapse had occurred four times worldwide on the same type of aircraft, and the accident this report concerns was the fifth such case. It was also the first case in Japan. The times of occurrence of the previous cases and measures taken by the manufacturer were as follows.

(1) April 1995 (First collapse accident)

During the landing roll of a MD-83 aircraft, while braking at around 50kt, the left MLG cylinder collapsed at the fuse section. The cylinder had accumulated 6,400 landings at the time.

After the accident, the manufacturer conducted flight tests using an MD-87 aircraft to determine the stress loading on the MLG cylinder during ground maneuvering. As a result, it was confirmed that the fuse section is loaded with a maximum stress of around 160ksi on landing, and Gear Walk occurs at around 40kt during strong braking, with the resulting stress on the fuse section rising to around 270ksi in the worst case.

Based on these results, the manufacturer issued SB (MD80-32A286) in September 1995 to carry out one time NDI of the fuse section. The SB also recommended installation of a restrictor in the brake hydraulic line.

The SB was later issued as a TCD. Based on the TCD, an NDI inspection of the collapsed cylinder that had been installed on JA8295 was carried out in December 1995.

(2) January 1996.

The manufacturer revised the SB (MD80-32A286) to Rev. 1. However, this was a minor amendment, and there was no change in the work to be performed.

(3) April 1997. (Second collapse accident)

During the landing roll of an MD-82 aircraft, while braking at around 60kt, the right MLG cylinder collapsed at the fuse section. The cylinder had accumulated around 10,000 cycles at the time, and 500 cycles since installation of the restrictor. Further, NDI had been conducted on the cylinder at around 500 and 1,600 cycles before the collapse.

The manufacturer revised the SB (MD80-32A286 Rev. 1) to Rev. 2 in October 1997, and incorporated an instruction to conduct NDI every 1,200 cycles until the cylinder accumulated 4,800 cycles.

The Company was advised by the manufacturer that it planned to issue Rev. 3 of the SB shortly and that an AD was expected to be issued based on the SB, so the Company did not carry out the NDI based on the SB.

The manufacturer stated as follows regarding the amendments to SB MD80-32A286 Rev.1.

1) The collapse had been caused by an undetectably small crack which had existed prior to the installation of the restrictor and had then propagated with the later use of the landing gear. Therefore, it was considered necessary to carry out NDI on the fuse section after installation of the restrictor.

2) The reason for the 1,200 cycle NDI inspection interval was to establish an inspection interval that could discover a crack before it developed to a length of 0.13 inches that could lead to collapse.

   The reason for ending inspections at 4,800 landing cycles was that, based on the above assumption, cracks on any cylinder should have developed to a detectable length by this number of cycles.

   From the second collapse accident up until the time the third collapse accident occurred, the manufacturer received reports from operators that inspection based on the SB had identified cracks on the fuse sections of four cylinders. Three of these cylinders had accumulated less than 4,800 cycles since restrictor installation. (The number of cycles on the remaining cylinder was unknown.)

(4) May 1998.

The manufacturer revised the SB (MD80-32A286 Rev.2) to Rev.3, and clarified the initial inspection period depending on landing cycles from installation of the restrictor, and the later repetitive inspection interval.

Thereafter, a TCD (TCD-4322A-99) was issued in May 1999 based on AD issued in April 1999 to enforce the SB. The cylinder that collapsed in this accident was removed from JA8295 in July 1999, and was overhauled. During the overhaul, NDI was carried out based on the TCD.

(5) February 1999.

The manufacturer revised SB (MD80-32A286 Rev.3) to Rev.4. The revision clarified that the 4,800 landing cycles referred to the time since installation of the restrictor. Further, the SB clarified that repetitive inspection should be conducted after more than 1,000 landing cycles since the previous inspection, and should be carried out a minimum of two times. There were no other changes in the SB content apart from these two items.

The Company conducted the second repetitive inspection of the MLG cylinder which collapsed in this accident in October 2000. At the time of its inspection, the cylinder had accumulated 1,077 cycles since it was previously inspected at overhaul.

(6) May 2001 (Third collapse accident)

The right MLG cylinder of an MD-83 aircraft collapsed at the fuse section on landing. The cylinder had accumulated a total of 20,100 cycles, and around 8,700 cycles since the installation of the restrictor.

An inspection found cracks in the fuse section of this aircraft's left MLG, which had been fitted to the aircraft at the same time as the collapsed right MLG.

In March 2003 the manufacturer issued a service bulletin (MD80-32A344) that an initial NDI should be conducted within 18 months or within 4,000 cycles after issued of this SB, and after that, repetitive inspections should be conducted when the number of landings reached 8,000 cycles, 12,000 cycles, 16,000 cycles and 20,000 cycles.

The Company received the SB in April 2003, and because the NDI had to be completed within 18 months or 4,000 cycles since issued of the SB, it made preparations to carry out the SB.

The manufacturer stated the following regarding issue of the SB.

1) This accident showed that cracks of previously undetectable length could grow to a detectable length more than 4,800 landing cycles. Consequently, it was necessary to conduct an inspection after 4,800 cycles.
2) From the third collapse accident, three crack growth speeds—"medium", "slow", and

"very slow"—were assumed, and NDI inspection intervals were established based on these assumed speeds.

3) Regarding the repetitive inspections continuing until 20,000 cycles, it was thought that based on the above assumptions, cracks on any cylinder would grow to a detectable length within this number of cycles.

(7) October 2003 (Fourth collapse accident)

While an MD-83 was taxiing for take-off, the left MLG cylinder collapsed at the fuse section. The cylinder had around 28,100 cycles at the time, and had accumulated around 16,000 cycles since installation of the restrictor.

This aircraft's operator had not yet carried out SB (MD80-32A344).

Three fatigue traces of different length were found on the fracture surfaces of the cylinder. The crack lengths were 0.08 inches in two locations, and 0.07 inches for the remaining fatigue trace.

(8) November 2003

An operator detected cracks at the fuse section of a cylinder by inspection based on the SB, and reported this to the manufacturer.

(9) December 2003

The manufacturer revised the SB (MD80-32A344) to Rev.1, and clarified that the time of the initial NDI inspection depended on the number of cycles after installation of the restrictor, but did not make changes regarding the repetitive inspection interval and the 20,000 cycle limit.

The Company received the revised SB on December 29, 2003.

(10) January 2004 (This accident.)

This was the fifth MLG cylinder collapse accident. The cylinder had accumulated a total of around 26,000 cycles, and 21,000 cycles since the installation of the restrictor.

Seven fatigue traces of different length were found on the fracture surfaces of the cylinder.

On January 28, 2004, the manufacturer revised to strengthen SB (MD80-32A344 Rev.1) to Rev.2, the NDI interval changed to every 450 cycles except for cylinders that had had a restrictor installed at the time of manufacture.

Furthermore, AD of the contents (2004-05-03) that carry out this SB are issued in February, 2004, and a TCD (TCD-6408-2004) was issued in March, 2004 on the basis of this AD.

The manufacturer stated the following regarding the issue of the SB.

1) From this accident, it was judged that there was a crack growth speed slower than "very slow".

2) Even though a single small crack of around 0.08 inches on its own would not cause

collapse, it was judged that several cracks are effectively the same as a large crack, and there is a possibility for the cylinder to collapse.

3) Assuming a "very slow" crack growth speed, it was judged that two NDI would be able to detect cracks before the MLG cylinder fractured during the time a crack could grow from the minimum detectable length of 0.0625 inches to 0.08 inches, at which length it is possible for collapse to occur if several cracks exist. It was therefore recommended that inspections be carried out every 450 landing cycles.

3. ANALYSIS

3.1 Crew Certifications

The captain and first officer had valid airman proficiency certificates and valid airman medical certificates in accordance with applicable regulations.

3.2 Certificate of Airworthiness

The aircraft had a valid certificate of airworthiness and had been maintained in accordance with applicable regulations.

3.3 Weather Conditions

It is estimated that weather conditions did not contribute to the accident.

3.4 Progress of the Flight until Touch Down

3.4.1 Speed and Rate of Descent at Touch Down

As described in section 2.1.1, the aircraft engines' EPRs began to decrease from a height of 60ft above ground level, and fuel flows attained idle values at 9ft above ground. Further, as described in section 2.16.3, IAS at touch down was around 133kt, rate of descent was around 2ft/s (0.6m/s), and vertical acceleration was around 1.2G. From these facts, it is considered that the landing was normal.

3.4.2 Time and Point of Touch Down

At 1623:47, the aircraft's radio altimeter indicated 0 ft and the spoilers deployed. A vertical acceleration also occurred, so it is considered that the aircraft touched down at that time.

From tire marks on the runway, it is estimated that the aircraft touched down around 570m from approach end of runway 01.

3.5 Situation after Touch Down

3.5.1 Time of the MLG Collapse

At 1623:48, immediately after touch down, the CVR recorded a sound of "Gashan", a "LANDING GEAR" voice warning, and a "BEEE" warning tone. It is estimated that these sounds were due to collapse of the left MLG cylinder and release of the landing gear down lock. It is therefore estimated that the left MLG cylinder collapsed at this time.

3.5.2 Left Wing's Contact with the Runway

At 1623:48, immediately after the aircraft touched down, the aircraft assumed a bank attitude of around 7° left. It is estimated that the left wing contacted the runway at this time, that the wing slid along the runway until the aircraft stopped, and during this period, that major structural components of the left wing were damaged by impact and so on.

3.5.3 Operation of the Brakes

According to DFDR data, the left and right brake pedals were depressed during 1623:54–55, and brake pressure increased. It is thought that the brake hydraulic lines of the left MLG were ruptured when the left MLG cylinder collapsed, but because hydraulic fluid loss was prevented due to the functioning of a limiter as described in section 2.17.2, brake pressure increased when the captain stepped on the brake pedals.

3.5.4 Captain's Actions after Landing

After the aircraft touched down, it is estimated that the aircraft did not leave the runway despite the collapse of the left MLG because the captain continued to apply right brake and carried out appropriate nose wheel steering.

3.5.5 Reverser Operation

The left engine was in a reverse condition at 1623:57, around 10 seconds after touched down, and the right engine at 1623:58. During 1624:02–03, the reversers on both engines momentarily stowed, but during 1624:04–05, the engines returned to reverse and remained in reverse until just before the aircraft came to rest.

It is thought that these events resulted from the captain momentarily stowing the reversers to correct the aircraft attitude back in place, then the captain felt that it would be difficult to make the aircraft stop within the runway distance remaining, so he operated reversers again. Also it is thought that the first officer felt same way and to urge the captain to attract attention, so he called "reverse" at 1624:03.

3.6 Damage to Left Engine Fan Blades

As described in section 2.12.2, the left engine's fan blades were damaged. It is estimated that this was the result of the engine ingesting pieces of the aircraft which were scattered while the aircraft was traveling with its left wing in contact with the runway.

3.7 Smoke in the Cabin

According to cabin attendant and passenger statements, smoke momentarily appeared in the cabin while the aircraft was traveling along the runway, but it is estimated that this smoke had dispersed by the time the aircraft came to rest. It is considered possible that hydraulic fluid, etc. leaking from the damaged brake hydraulic lines was ingested into the engines and heated by hot high-pressure air inside the engine, causing the smoke.

3.8 Inspection of the MLG Cylinder

3.8.1 Company Inspection of the Cylinder

The company carried out NDI of the cylinder based on TCD-4322-95 in December 1995. Also, when the Company transported the cylinder to the repair station for overhaul, it directed the repair station to carry out TCD-4322A-99 as described in paragraphs 2.17.8(2) and 2.17.11(4). Then the Company fitted the overhauled cylinder to the aircraft, and later carried out repetitive NDI in accordance with the TCD.

The Company was also making preparations to carry out another SB (MD80-32A344) issued by the manufacturer, since there was a time limit before which it had to be carried out.

As a result of above, it is considered that the Company had inspected the cylinder in accordance with the TCD/SB, and that there were no problems with its inspection process.

3.8.2 Inspection by the Repair Station

As described in section 2.17.5, the repair station conducted NDI inspection of the fuse section of the cylinder during its overhaul as directed by the Company. This inspection was a partial inspection of a specific section after removal of the plating. Usually, NDI of the whole cylinder conducted during overhaul is limited to magnetic particle inspection, and it is thought that compared to this, the additional NDI would be more capable of detecting cracks.

As described in section 2.17.8, the repair station's NDI equipment was calibrated and the NDI inspectors were qualified. It is estimated that the inspection by the repair station was carried out in accordance with the method recommended by the manufacturer.

3.8.3 Collapse of the Cylinder

The cylinder on the aircraft collapsed after around 6,760 landing cycles from the previous inspection carried out by the Company (in October 2000).

As described in section 2.16.1, the length of the largest fatigue crack on the fracture surface of the collapsed cylinder was measured at around 0.20 inches. This was greater than the crack length of 0.13 inches which the manufacturer had stated could lead to collapse. It is estimated that the weakened cylinder was unable to withstand the stresses on the fuse section due to the impact of landing and spin-up[*14], and collapsed.

Because there had been no opportunity to inspect the fuse section established by the manufacturer since the Company had conducted its last inspection, it is considered that there was no opportunity to detect the growth of the crack.

3.9 Manufacturer's Actions

3.9.1 After the First MLG Collapse Accident

As described in section 2.17.11(1), after the first MLG collapse accident, the manufacturer issued SB (MD80-32A286) to execute NDI of the fuse section of the cylinder and to recommend the installation of restrictors in brake hydraulic lines. ARAIC considered that this was because the manufacturer thought that repeated loading of the cylinder by Gear Walk was a factor in the collapse and that installation of restrictors in the brake lines would prevent this, and if there were no cracks at the time of the restrictor installation, they would not subsequently occur.

Moreover, a TCD based on AD was issued by the Japan Civil Aviation Bureau to execute the SB.

3.9.2 After the Second MLG Collapse Accident

As described in paragraph 2.17.11(3), a second MLG collapse occurred on the cylinder that had equipped with the restrictors and had executed NDI.

ARAIC estimated that the manufacturer judged that small undetectable cracks generated before installation of the restrictors grew during subsequent landing cycles, causing collapse of the cylinder, and so issued SB (MD80-32A286R2) which required repetitive NDI of the cylinder fuse section. The SB stated that repetitive inspection should be carried out at 1,200 landing cycles intervals until 4,800 landing cycles after restrictor installation. However, this SB was later revised (MD80-32A286R3), and the AD and TCD based on the SB was also revised. The revised TCD stated that twice NDI should be carried out on cylinders with greater than 2,400 landing cycles, with the first

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[*14] Spin-up means that the increase in a wheel's speed from non-rotating to the same as the aircraft's speed after landing. During this period, the landing gear experiences an aft-wards force.

inspection within 1,200 landing cycles from the effective date of TCD, and the second within 1,200 landing cycles thereafter. As a result of this, NDI was carried out on the cylinder at around 13,400 cycles and around 14,500 cycles after restrictor installation.

During the approximately four years between the second and third MLG collapsed accidents, four cylinders cracks were detected in the fuse sections of by the SB (MD80-32A286 and subsequent revisions). It is considered that the manufacturer judged that the measures of the SB were able to accurately detect cracks.

3.9.3 After the Third MLG Collapse Accident

ARAIC estimated that as a result of the third MLG collapse accident described in paragraph 2.17.11(6), the manufacturer judged it was also necessary for an inspection to be made after 4,800 landing cycles after restrictor installation, and issued a service bulletin (MD80-32A344).

ARAIC estimated that the manufacturer assumed a crack growth speed based on the third collapse case and established an NDI inspection interval.

Moreover repetitive NDI was terminated after 20,000 landing cycles, ARAIC considered that the manufacturer thought that based on the [crack growth speed] assumption, cracks on any cylinder would be detected by the time this number of cycles was reached.

However, it was about a year and 10 months from the third MLG collapse accident until this SB was issued, and during that time, there was no opportunity to carry out NDI on the cylinder of the aircraft.

After that, cracking continued to be detected with a further two cases, and after the fourth MLG collapse occurred, the manufacturer further revised the SB, and changed the time within which the SB should be carried out from 18 months/4,000 cycles from issued of the SB to a time depending upon the operating condition of the cylinder. However, the limitation of repetitive NDI expired until 20,000-cycle was not changed.

Since the cylinder collapsed three days after the Company received the SB, ARAIC considered that this accident would not have been prevented if the Company had decided to carry out NDI within six months of issue as specified in the SB.

3.9.4 After this MLG Collapse Accident

After this accident, the manufacturer revised the SB to conduct NDI of the cylinder fuse section every 450 landing cycles (MD80-32A344R2).

Moreover, a TCD based on AD was issued by the Japan Civil Aviation Bureau to execute the SB.

ARAIC estimated that the based on the fatigue traces on the collapsed cylinder's fracture surfaces, the manufacturer judged that there was the crack growth speed lower than that calculated from the third MLG collapse accident. Furthermore, based on the fourth MLG collapse, ARAIC estimated that the manufacturer had judged that even though a single 0.08-inch length crack would not lead to cylinder collapse, multiple cracks of that length would be have the same effect as a large crack, and it would be possible for the cylinder to collapse.

Therefore, ARAIC estimated that the manufacturer considered that two or more NDI inspections were necessary during the time cracks could grow from the 0.0625-inch minimum detectable length to a length of 0.08 inches when it would be possible for a cylinder to collapse, and assuming a "very slow" crack growth, the manufacturer judged that it would be appropriate to conduct NDI every 450 landing cycles.

3.10 Investigation of the Cylinder

3.10.1 Cylinder Material

As described in section 2.16.1, the collapsed cylinder was sent to the manufacturer, and investigations were conducted concerning the material, the cylinder's dimensions and etc. As the result, it was found that the cylinder was manufactured in conformity with the manufacturer's specification. Further, as described in section 2.16.2, an additional investigation of the cylinder conducted with the assistance of the NIMS confirmed that there was no abnormality of the cylinder material.

3.10.2 Shot Peening and Grit Blast

As described in NOTE 6 of 2.16.1, shot peening process has been established to increase the fatigue strength of metal material, and also as described in NOTE 4 of 2.16.1, the grit blast process has been established as standard work prior to plating.

Therefore, it is thought that the grit blast could not have large influence on the fatigue strength of metal material if the shot peening and grit blast is accomplished properly.

As stated to 2.16.2 (3), since the hardening layer of approximately 0.2mm in thickness was confirmed on the cylinder surface as a result of the hardness examination (the Vickers method), which was performed by NIMS, it is thought that shot peening was properly performed to the cylinder.

However, the residual compressive stress with shot peening may be relaxed when it receives a strong stress, so it is thought about possibility that the residual compressive stress was lost at fuse section due to intense vibration by the Gear Walk, which occurred prior to the restrictor was installed into the main landing gear.

3.10.3 Roughness and surface flaw of cylinder

As described in section 2.16.1 (2) and 2.16.2 (4), roughness and surface flaw were found on the surface of the cylinder. It was also confirmed that the aluminum oxide used in grit blast were found embedded in a part of surface.

It is thought that surface roughness is caused by shot peening or grit blast in the process of the time of manufacture or repair of the cylinder. Moreover, it is considered possible that the surface flaw was caused by improper grit blast which was performed in the process of the time of manufacture because there is no other possible force to be applied to the cylinder surface except grit blast.

It is considered possible that the other portion than the fractured surface of the cylinder had a grain of an aluminum oxide embedded in a base metal and plastic deformation (plastic flow). As mentioned in 3.11, it is considered possible that these are caused high pressure of the aluminum oxide grain by the grit blast at the time of the manufacturer before the MLG experienced Gear Walk.

3.10.4 Effect of surface flaw of the cylinder

As described in section 2.16.2 (5), the test specimen, prepared for the fatigue strength test, cut from the material of the inside of the cylinder was not collapsed from surface with high stress though no shot peening treatment and no residual compressive stress. While the test specimen, cut from cylinder surface , collapsed from surface at above a certain stress originated on the surface flaw.

From this test result, it is thought that whether or not residual compressive stress caused by shot peening, the test specimen will collapse from inside if there was no surface flaw on the cylinder.

As described in section 2.16.2 (1), the all traces of fatigue which was remained in the collapsed cylinder of the aircraft occurred from surface, and no foreign materials were found in the around of the origin of the traces.

Therefore it is thought when the aircraft's MLG suffered serious vibration in the test flight after manufacture, the crack originated on the surface flaw occurred on the cylinder by improper grid blast, then the crack grew during normal use, and the cylinder was broken. Moreover, as described in section 3.10.2, it is also considered possible that the loss of residual compressive stress did not constrain growth of the crack.

High-strength steel is sensitive to surface flaw, the existence of flaw influences fatigue strength, so the manufacturer of aircraft and it's components, and maintainer should pay adequate attention to avoid generating the surface flaw when maintenance or repair working.

3.11 Specification of the grit blast

As described in 2.17.9, the specifications of the grit blast perform prior to plate is different between the manufacturer and the repair company, etc. It is thought that manufacturer's standard or repair companies standard are used because there is no standardization specifications in the grit blast.

The standard of the repair company is almost the same as the standard of the manufacturer specification excluding sprayed pressure. As described in section 3.12, this specification is established in the titanium cadmium plating specifications by the repair company.

The other companies that is repair the landing gear of large aircraft to carried out the grit blast by manufacture(differ from the manufacturer of this plane) specification. But blast pressure is used to lower value in the standard because the trouble occurred in the past.

Concerning the description of 3.10.3, it is considered possible that the high pressure of the grid blast generated the flaw which led to fracture because the restrictor valve was installed after the aircraft experienced the Gear Walk. From this, it is considered possible that the pressure of the grid blast at the time of manufacture was too high.

3.12 Specification of titanium cadmium plating

The high-strength steel used for the cylinder etc. are affected by the hydrogen embrittlement[*15] easily, so the low hydrogen embrittlement cadmium plating (unbrightend cyanide process) has been done so far. However, recently the titanium cadmium plating to which the hydrogen embrittlement doesn't occur easily has come to be used generally.

[*15] A hydrogen embrittlement meaning is phenomenon of the toughness of the steel material decreasing with the hydrogen absorbed in the steel.

The repair company also manufacture the landing gear of the aircraft. So repair company established the procedure of the titanium cadmium plating before and applied to manufacturing landing gear etc. This method is almost equivalent to the method by manufacturer of the aircraft and approved by Civil Aviation Bureau of Japan.

It is estimated that the repair company decided to apply the plating in accordance with repair company procedure because the titanium cadmium plating is not specified for the overhaul manual of the manufacturer. So repair company uses the own standards.

It is thought that the application of the titanium cadmium plating to the cylinder did not contribute to the accident.

3.13 Cylinder Inspection Method established by the Manufacturer

When the first cylinder collapse accident occurred, the manufacturer issued an SB to carry out a one time inspection of the cylinder fuse section. However, MLG collapses continued to occur, and on each occasion the manufacturer revised the SB or issued another SB. In spite of this, however, this accident was not prevented.

After the first MLG collapse accident, the manufacturer's investigation determined the length of the fatigue crack traces and material characteristics, and from these the manufacturer estimated a crack growth speed and established an inspection interval. However, because [the inspection regime] used a hypothesis that was based on a limited amount of data, the hypothesis differed from reality, led to the subsequent main landing gear cylinder failure.

3.14 Response of Emergency Services

As described in section 2.14, firemen who witnessed the abnormal condition when the aircraft landed, followed the aircraft in two fire engines, and one fire engine applied fire-suppressing foam immediately after the aircraft came to rest, and this response was appropriate. The airport firemen usually observed all scheduled landings and take-offs, and it is estimated that because of this, they were immediately able to respond appropriately in this accident. Further, it is estimated that accident occurrence training was conducted around one month before the accident, this contributed to that the smooth response of airport control office personnel, fire fighting personnel and airport staff.

3.15 Functioning of the Emergency Evacuation Equipment

Immediately after the aircraft came to rest, it is estimated that the captain ordered the cabin attendants to prepare for an emergency evacuation and to deploy the escape slides as a precaution. Following this command, it is estimated that the cabin attendants deployed the slides at the aft service door (left) and the aft passenger exit. It is estimated that cabin attendants did not deploy the forward right slide because the aircraft's inclination made [evacuation from this exit] dangerous. Further, it is estimated that cabin attendants did not deploy the forward left slide because they were able to extend the air stairs. It is therefore estimated that the slides functioned normally except apart from the left and right forward slides, which were not used.

3.16 Evacuation of the Aircraft

As described in section 2.15.2, all but the forward escape slides had been deployed, but the captain did not use these slides to evacuate the passengers. It is estimated that the captain did judged that the situation did not require an emergency evacuation for the following reasons.

(1) The crew deployed the slides assuming a fire might occur, but fire-suppressing foam was applied by a fire engine that had rushed to the scene, and although smoke had appeared in the cabin momentarily it had dispersed, so the crew judged that there would be no outbreak of fire.

(2) Though the fuselage was inclined to the left, the angle was around 10° as described in section 2.1.1, and the crew did not think this abnormal.

(3) During the period between touch down and the aircraft coming to rest, the crew had not felt any large shocks.

Further, it is thought that because the captain thought that the air-stair was useable, and there was a strong chance of passenger injury if they evacuating using the slides, the captain made the passengers disembark using the air-stair as normal.

Several passengers who had been unable to disembark due to slope of the air-stair were assisted in leaving the aircraft by the crew with the help of the firemen who had rushed to the scene. It is therefore estimated that there was appropriate coordination between both parties relating to the passenger evacuation.

After the passengers had disembarked, the first officer directed them to the upwind side of the aircraft, which is considered safe if there is an outbreak of fire. The directions of the first officer were appropriate.

As described in section 2.15.1, it is estimated that it took about ten minutes for all persons to disembark. It is estimated that the passengers did not escape from the aircraft in a hurry because there was a possibility of injury when leaving the aircraft in a hurry due to the slope of the air-stair as a result of the inclination of the fuselage which made the footing unstable, and because there was no need for a rapid evacuation.

It is estimated that the confirmation that all persons had left the aircraft was carried out by the captain and cabin attendants. From the above, it is estimated that an emergency evacuation was not carried out in this accident, but that passenger disembarkation was performed in accordance with the standard procedures for emergency evacuation described in section 2.15.3.2.

3.17 Causes of Passenger Injuries

As described in section 2.13, three passengers were injured in the accident. As described in section 2.1.1, since the vertical acceleration at landing was 1.2–1.3G, it was not an unusually hard landing, and further, since it is estimated that the aircraft continued almost straight after landing, there were no large fore/aft or left/right accelerations that could cause serious injury. Though the three passengers who were injured were seated on the left side of the aisle, their seat positions were distributed along the length of the aircraft, the cause of their injuries could not be identified.

4. PROBABLE CAUSE

In this accident, it is estimated that due to the left main landing gear cylinder collapsed immediately after the aircraft landed at Tokunoshima Airport, the fuselage inclined to the left and the aircraft traveled with its left wing in contact with the runway surface, resulting substantial damage.

With respect to the collapse of the MLG cylinder, it is considered that Gear Walks which experienced before the restrictor was installed generated large stresses on the fuse section of the cylinder surface and caused micro cracks. The micro cracks are considered to grow during normal operation and eventually lead to the fracture.

Further, it is considered that the presence of surface flaw on the cylinder caused by grit-blast contributed to the crack generation.

And the contributing factor to the fact that the company could not detect the cracks on the cylinder by the scheduled maintenance, etc. is considered to be that the manufacturer had not established appropriate inspection intervals or inspection times to detect fatigue cracking.

5. Comments of the United States of America

The Accredited Representative of the United States of America, the state of Design and Manufacture has provided the comments on the report.

In accordance with paragraph 6.3 of Annex13 to the Chicago Convention, ARAIC has appended the comments which had not been reflected in the report.

(See Appendix 2)

Figure 1　Accident Site

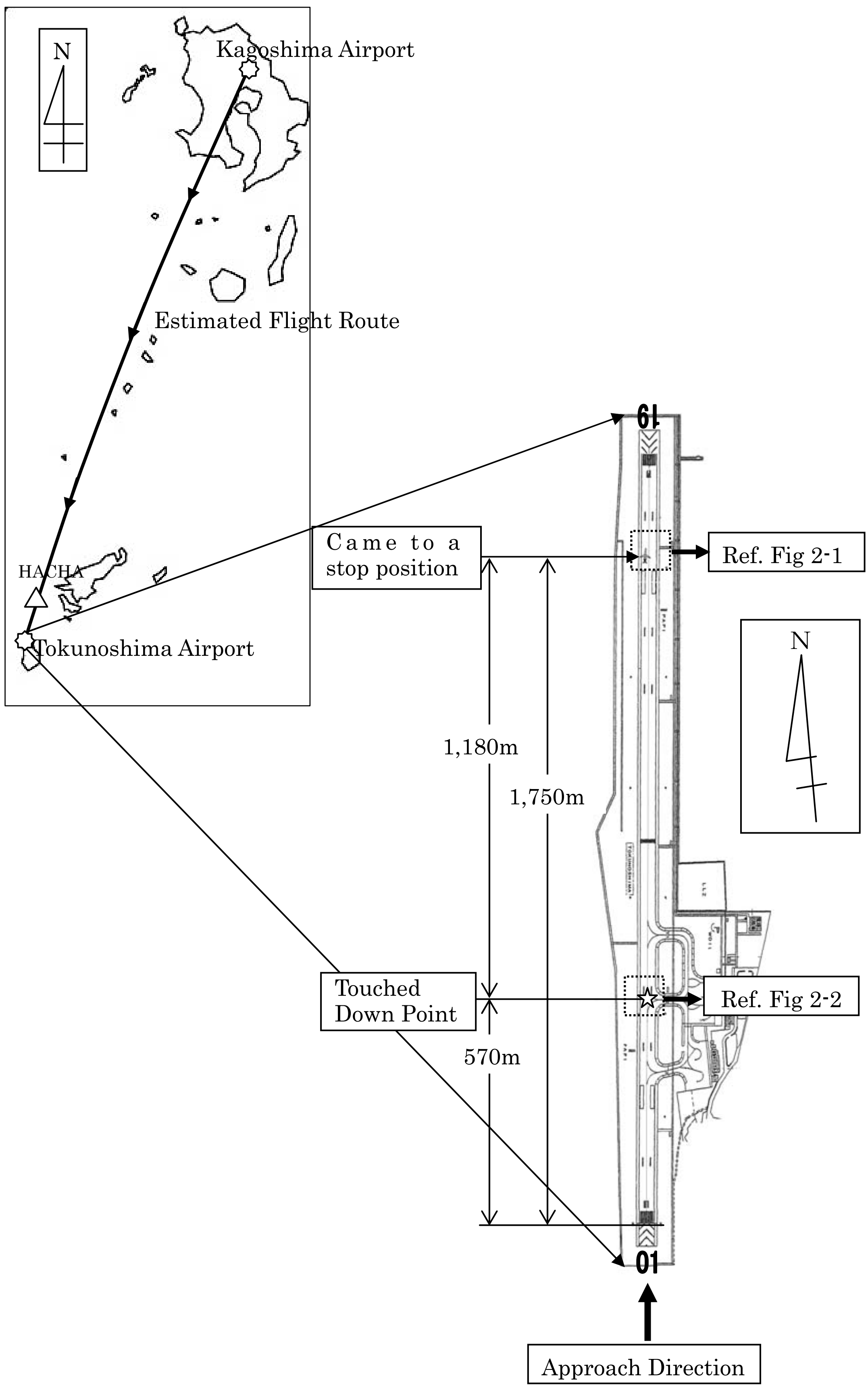
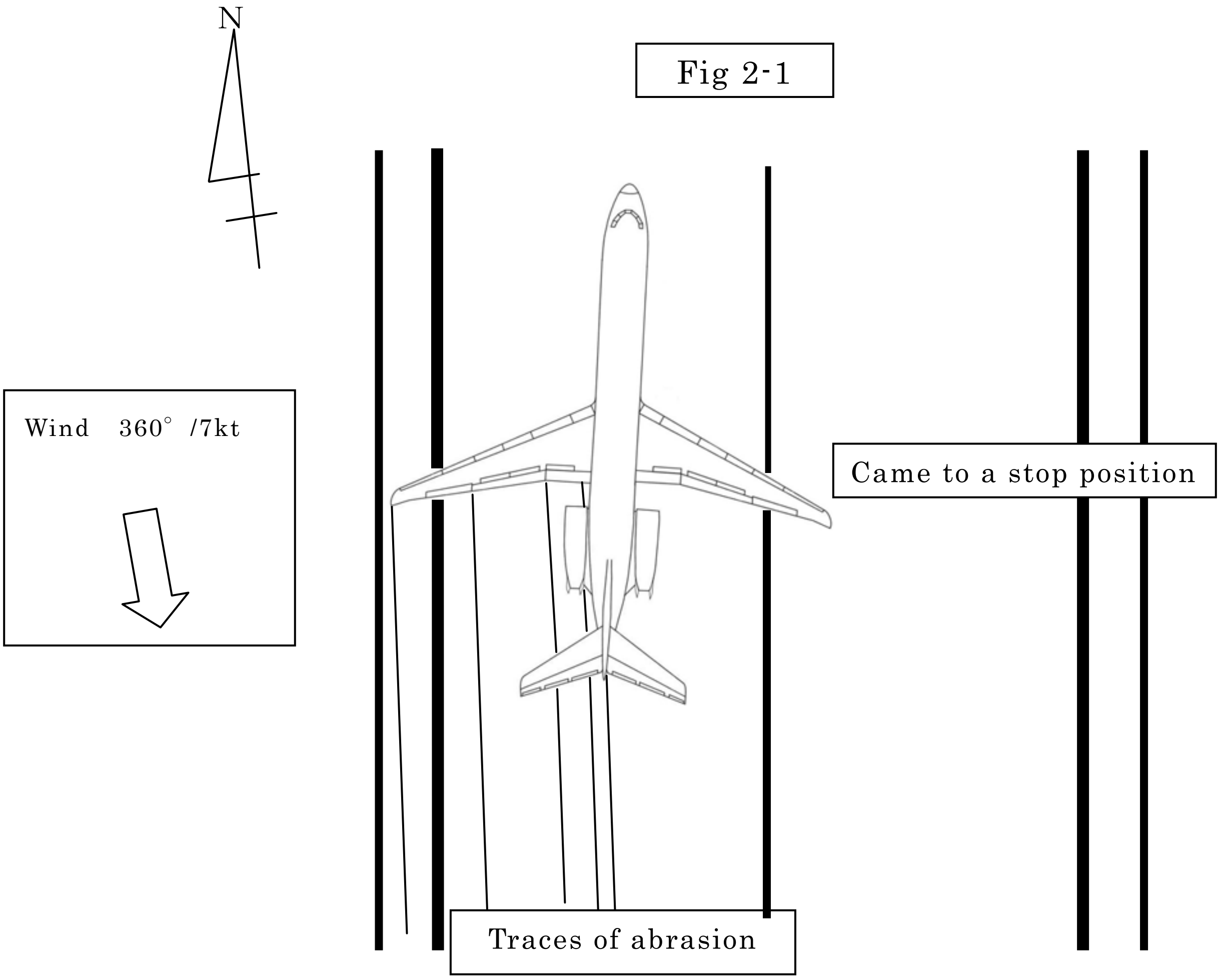


Figure 2 Traces on the Runway



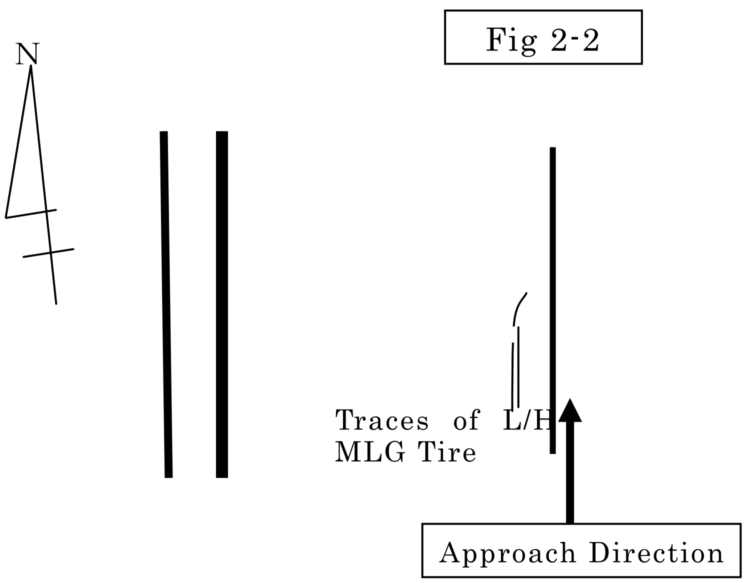


Figure 3　　Douglas DC-9-81 Projection Chart

Unit : m

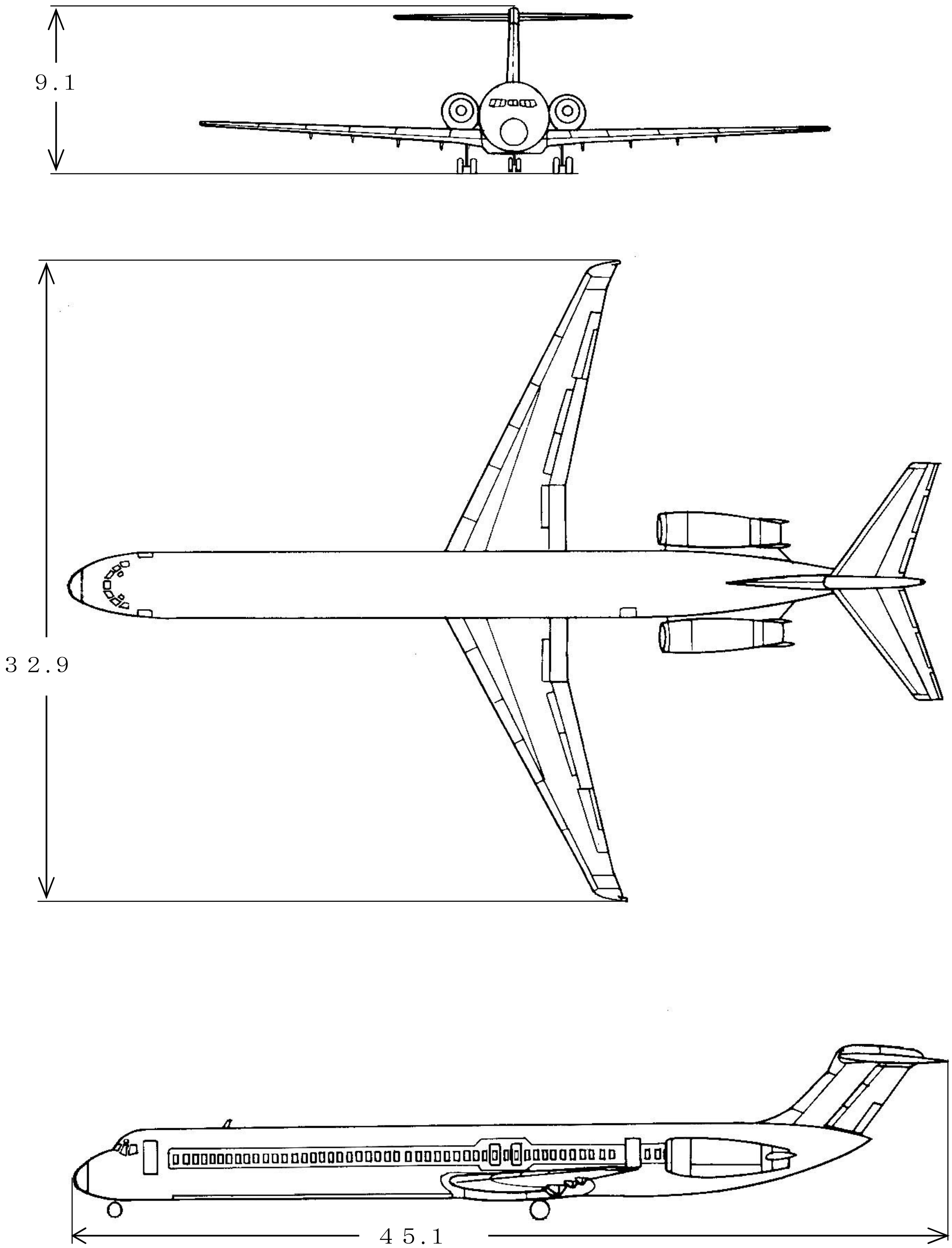


Figure 4 Main Landing Gear Cylinder

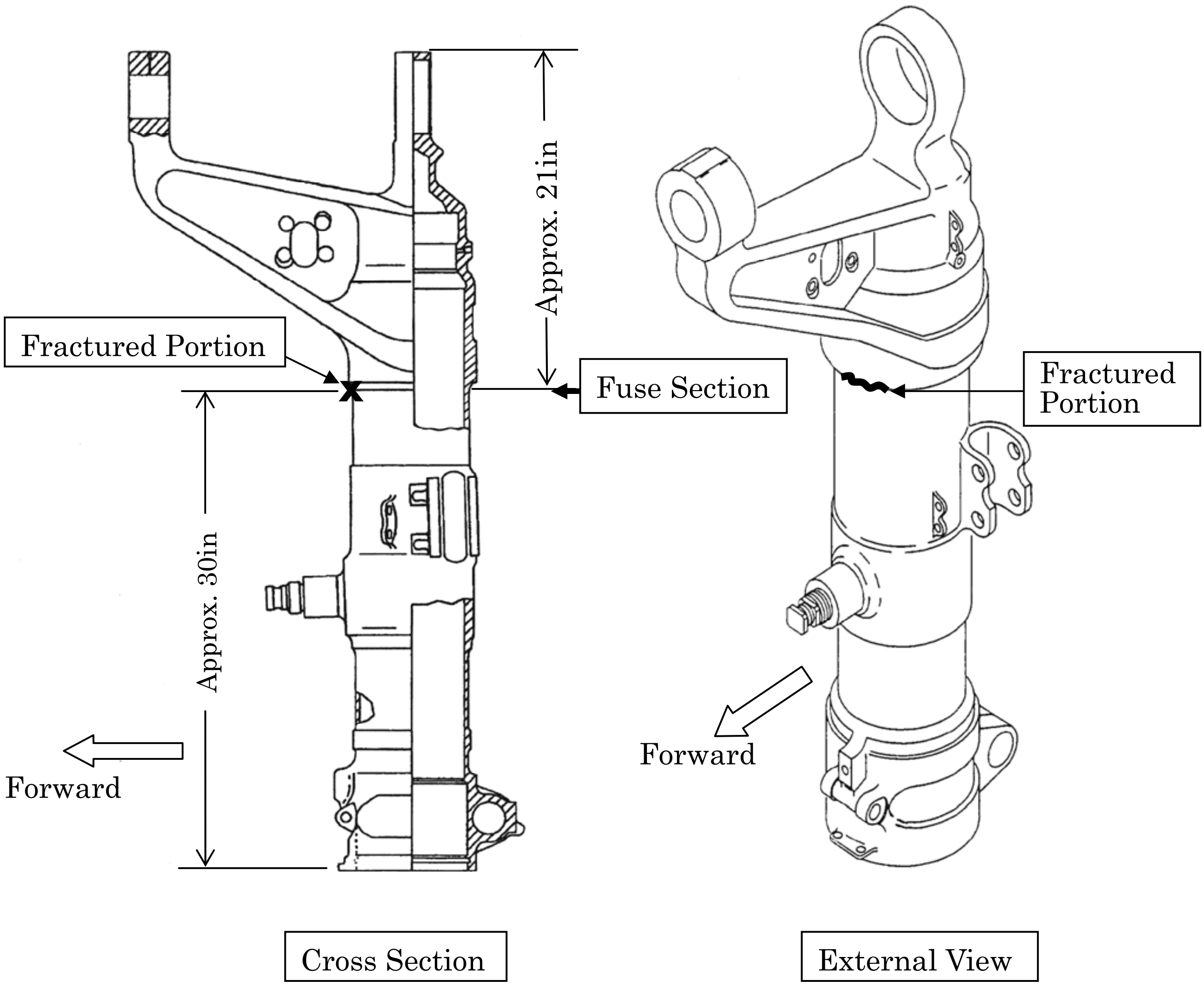


Photo 1 The Aircraft

Photo 2 The Aircraft (Rear View)

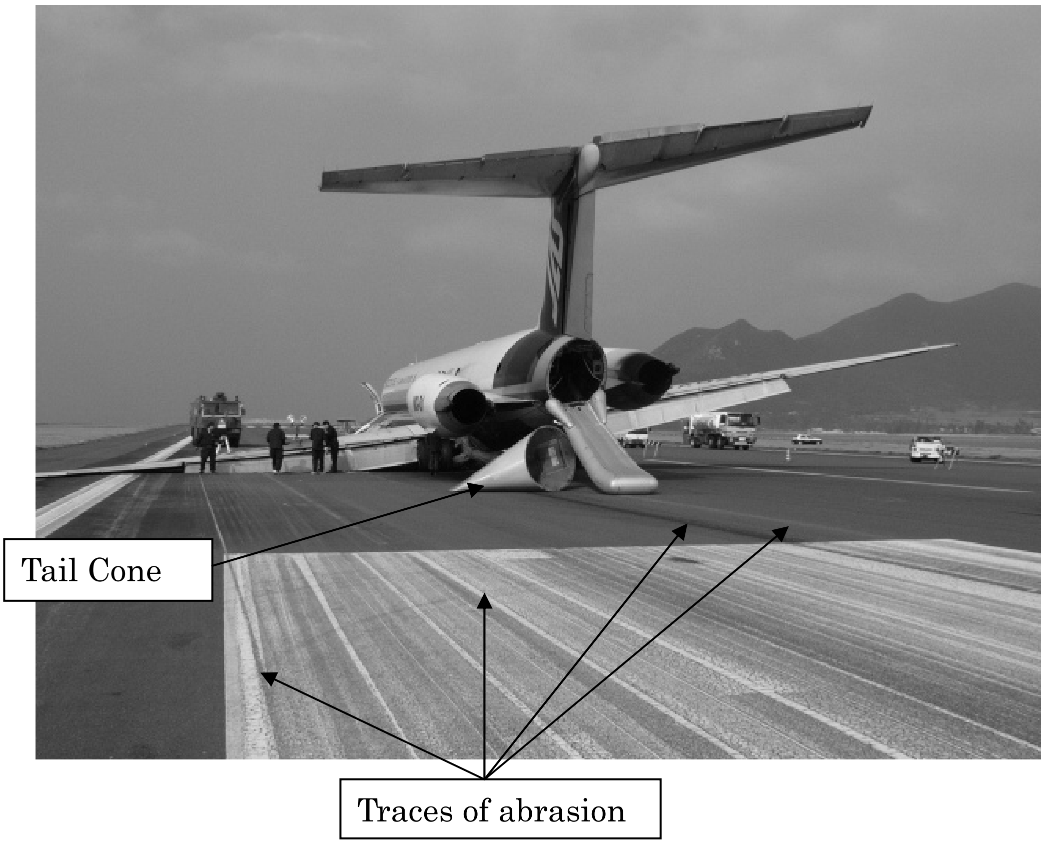


Photo 3 Major Damages

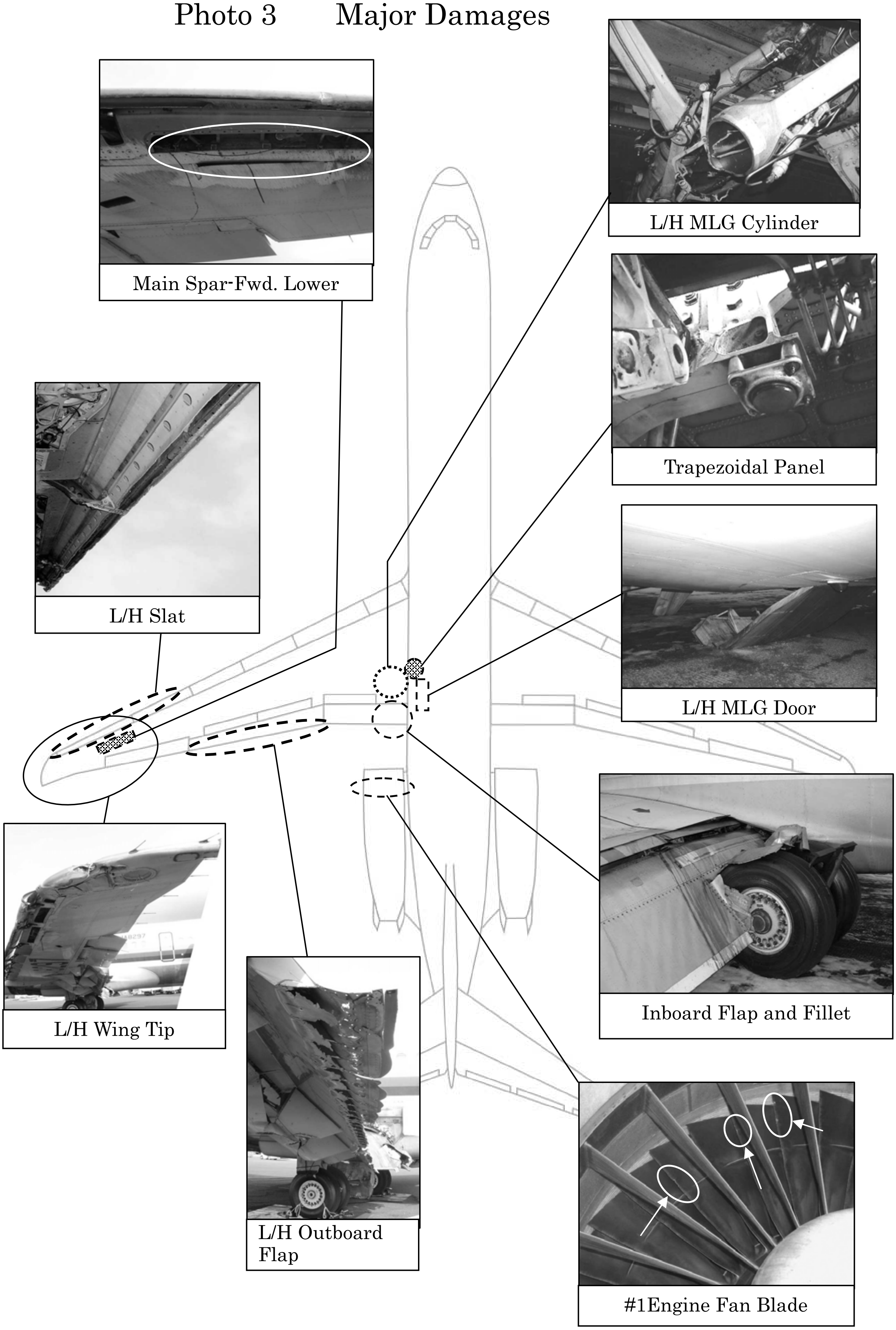


Photo 4　Deform of L/H Fwd Lower Spar

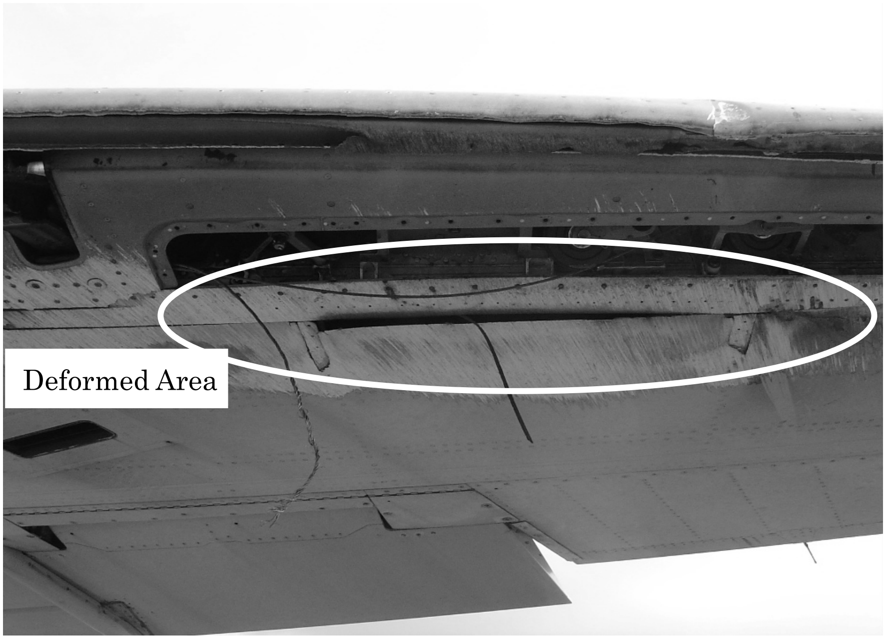


Photo 5　Damage of Trapezoidal Panel

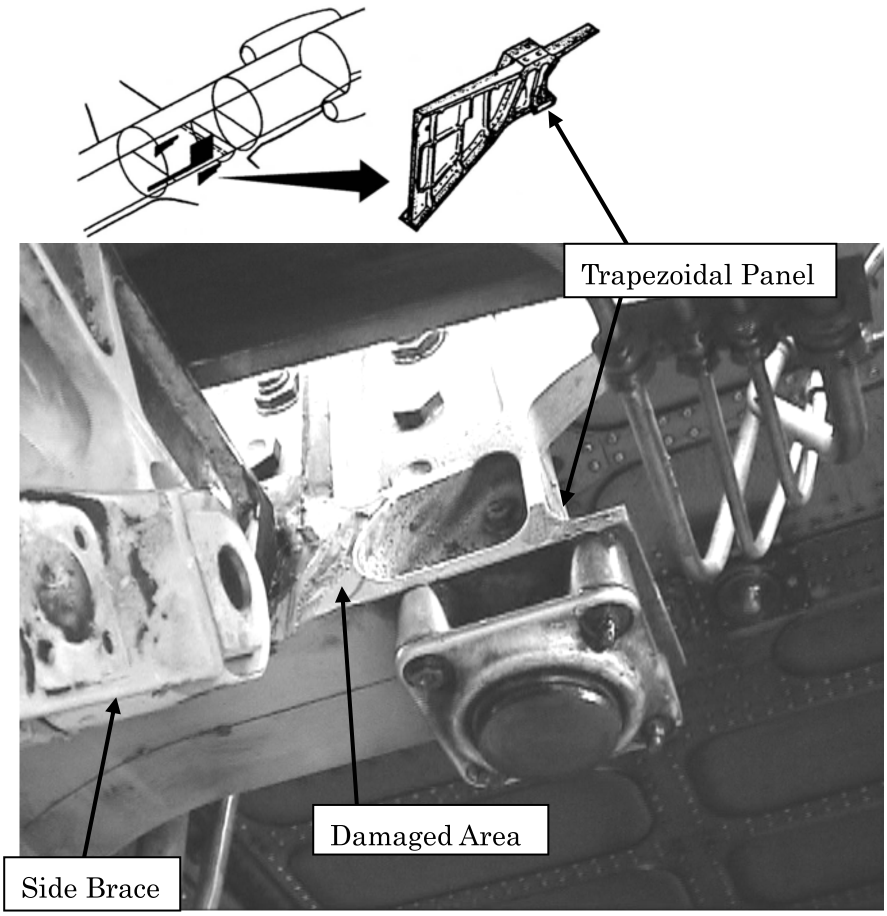


Photo 6　Fractured of L/H MLG Cylinder

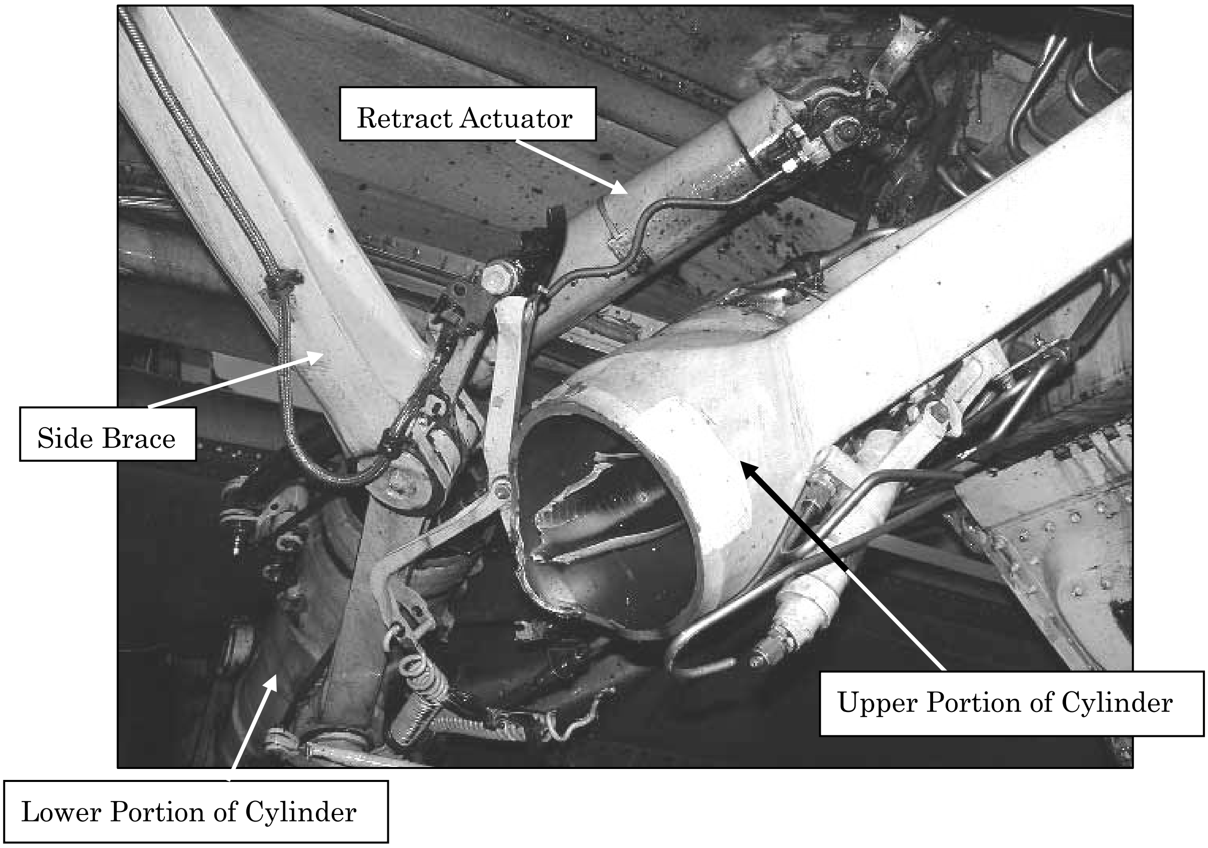
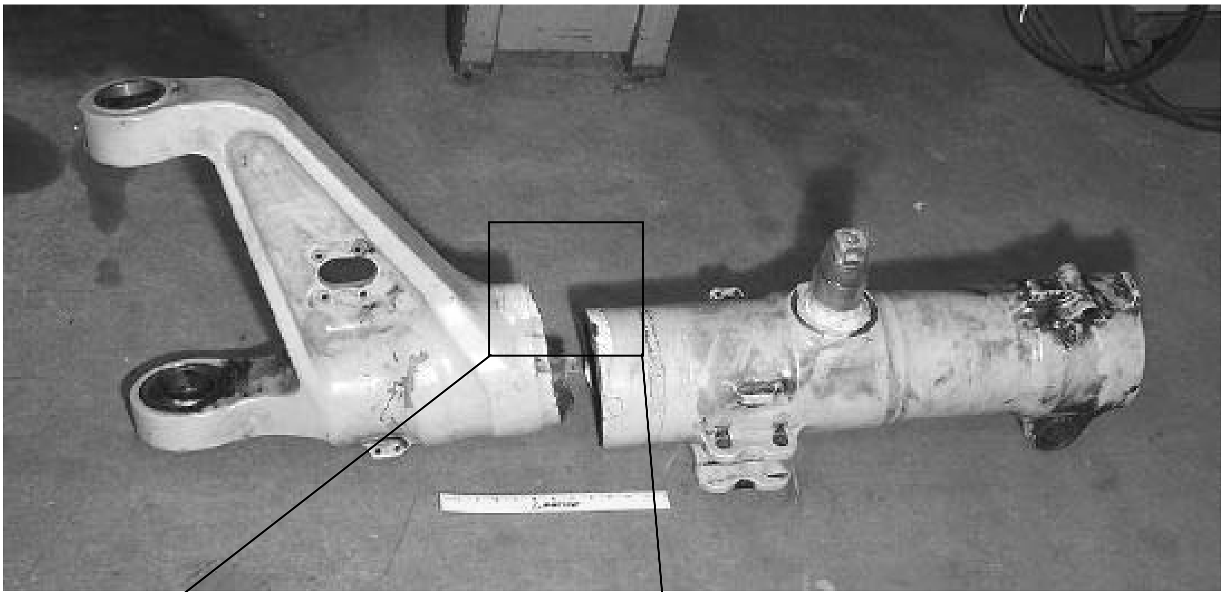


Photo 7　Fan Blade Damages

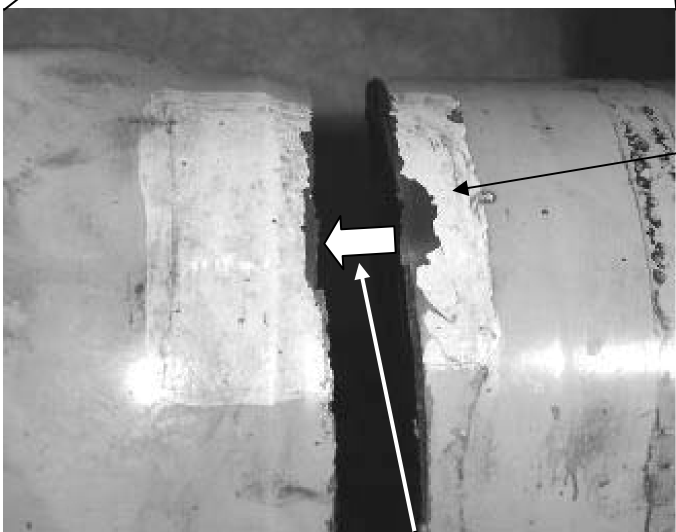
Photo 8　Fractured Cylinder

(Photo by NTSB)

Overview



Close Up



Painted portion after performed NDI by the company

Bold arrow shows the direction of the observation where fractured surface shown in photo 9

Photo 9　Fractured Surface

(Photo by NTSB)

* Upper portion of the cylinder

(The observation from the direction of the bold arrow shown in photograph 8)

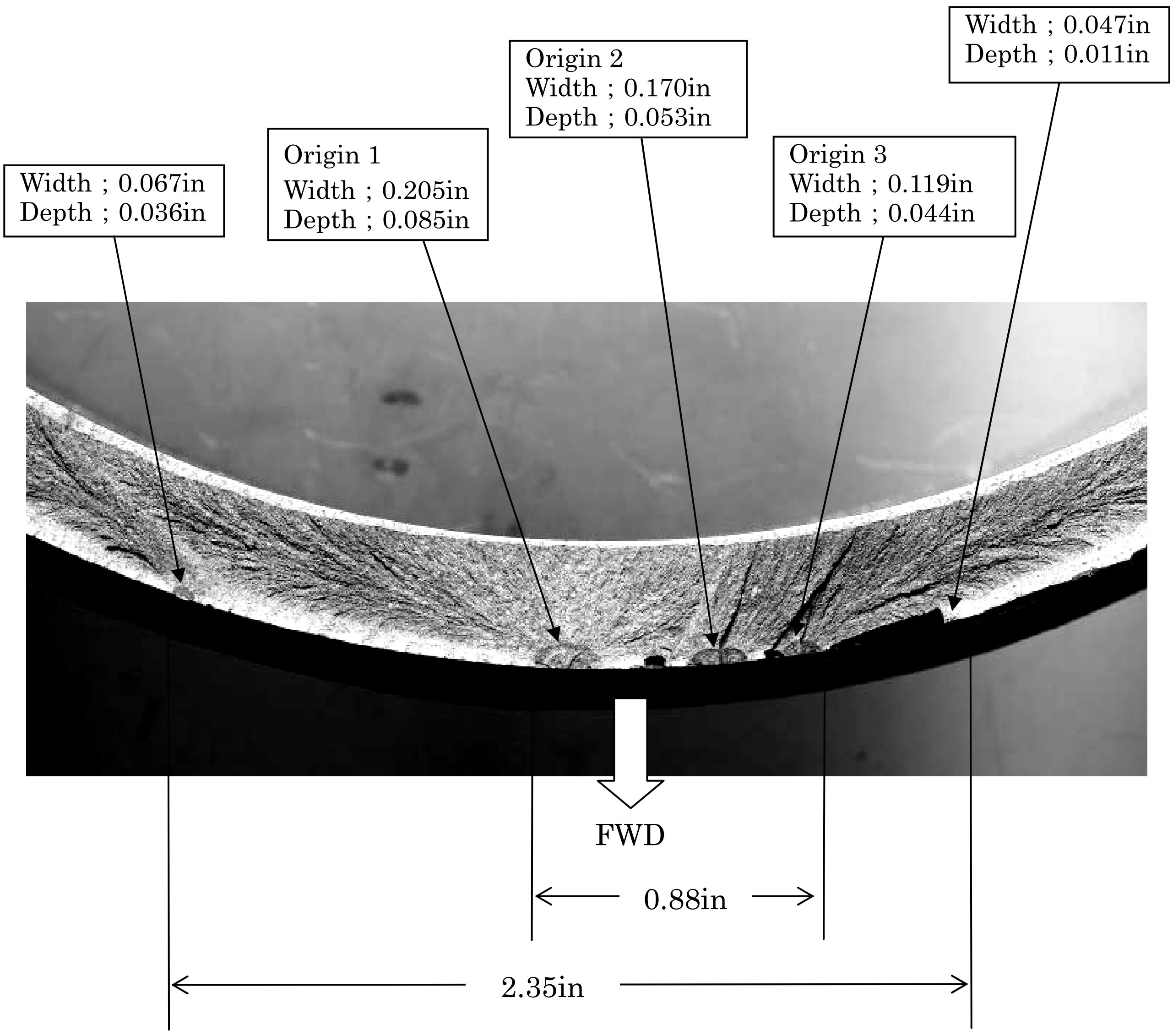


Photo 10　SEM Fractograph of Origin 1

(Photo by NTSB)

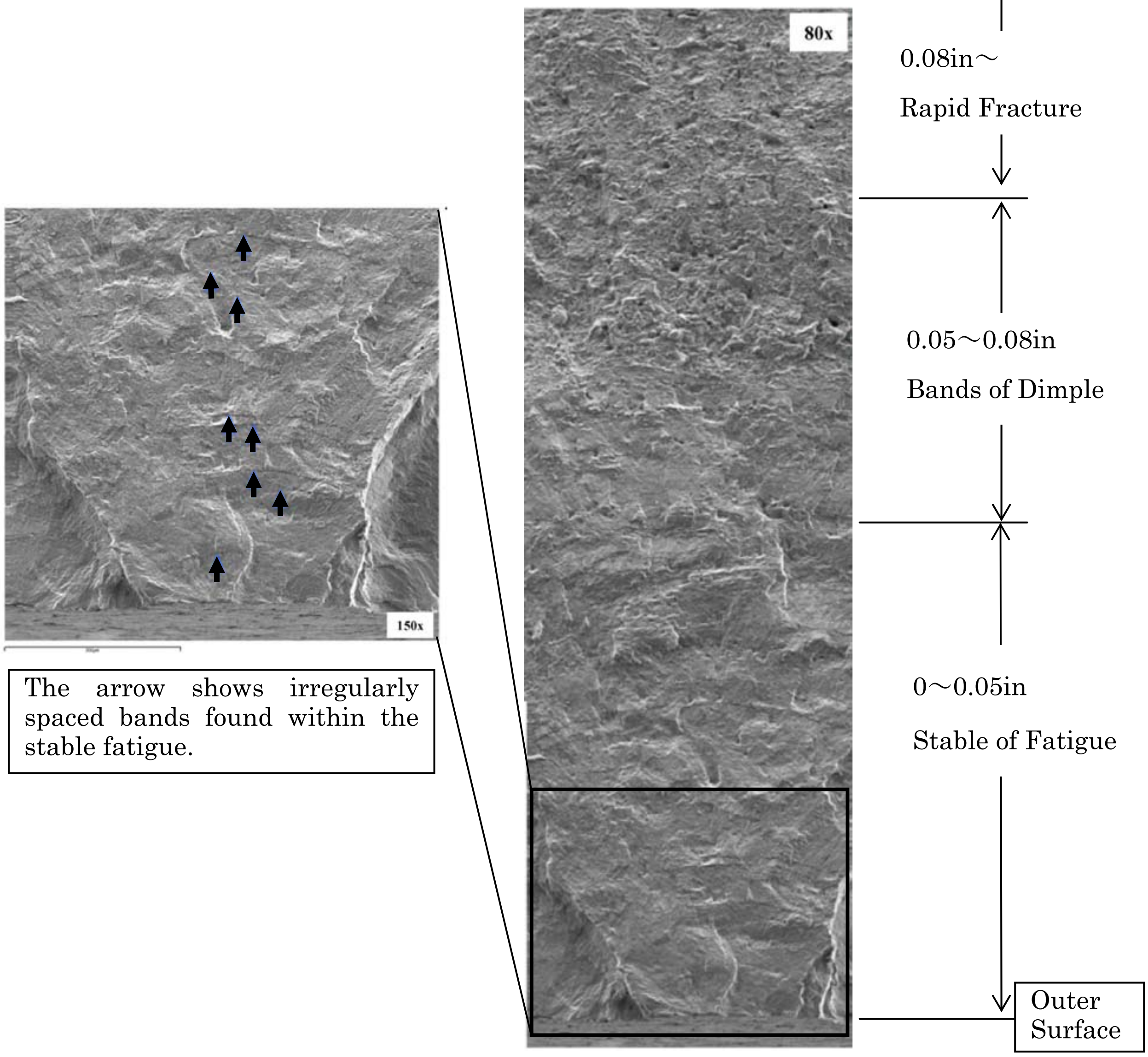
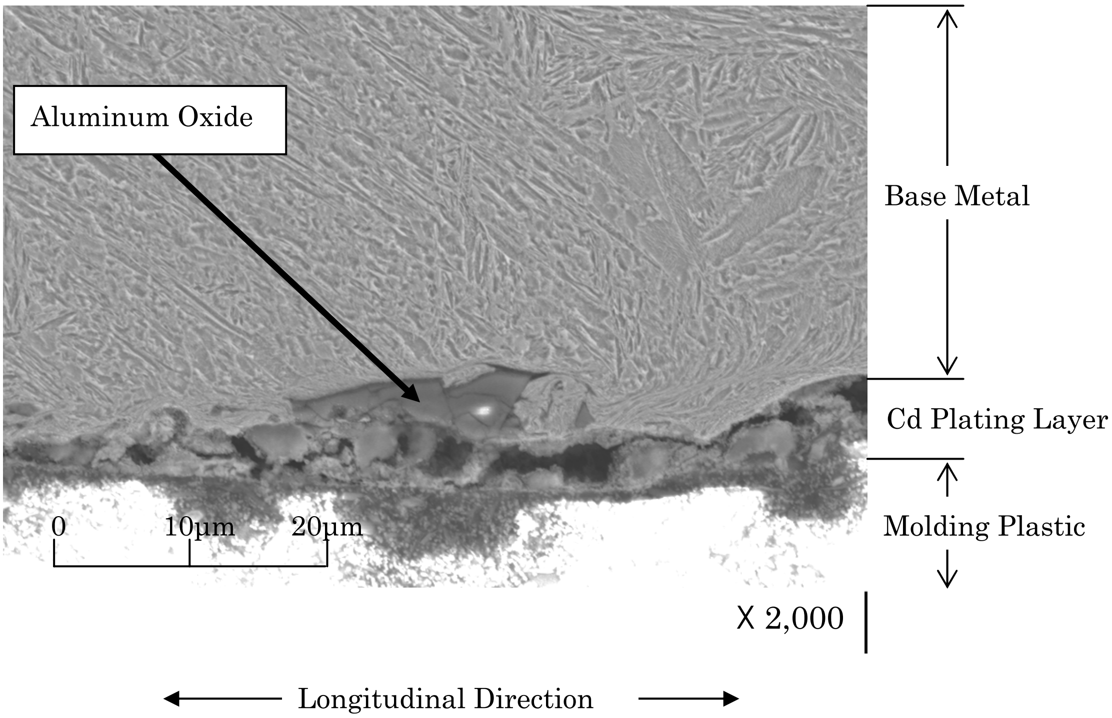


Photo 11

Trapped Aluminum Oxide in the Cylinder Surface

(Photo by NIMS)



Close Up

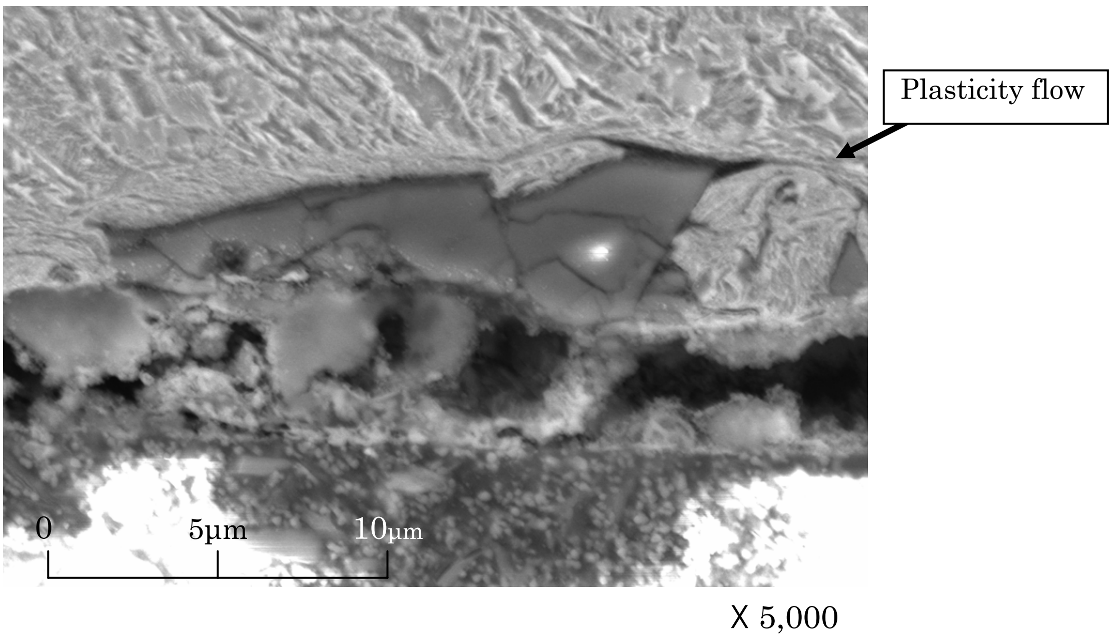
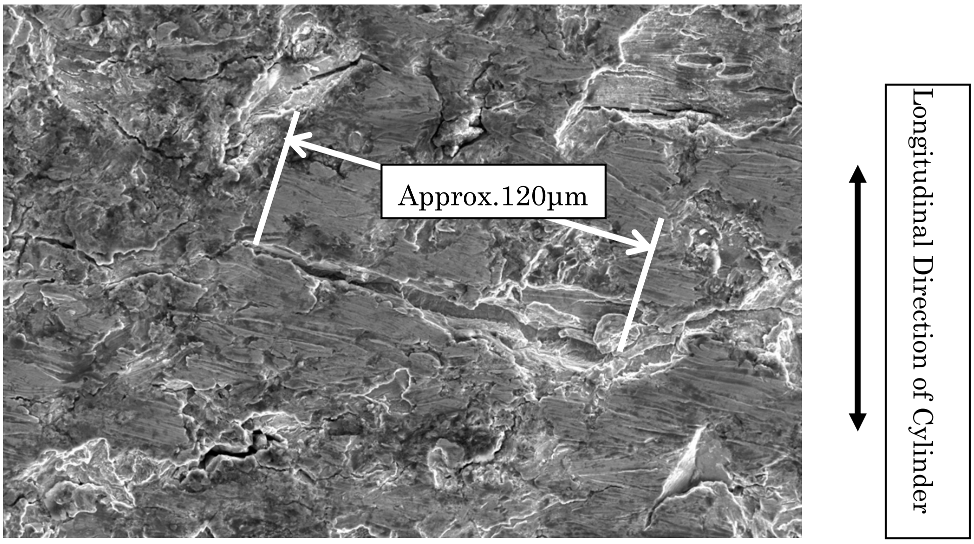
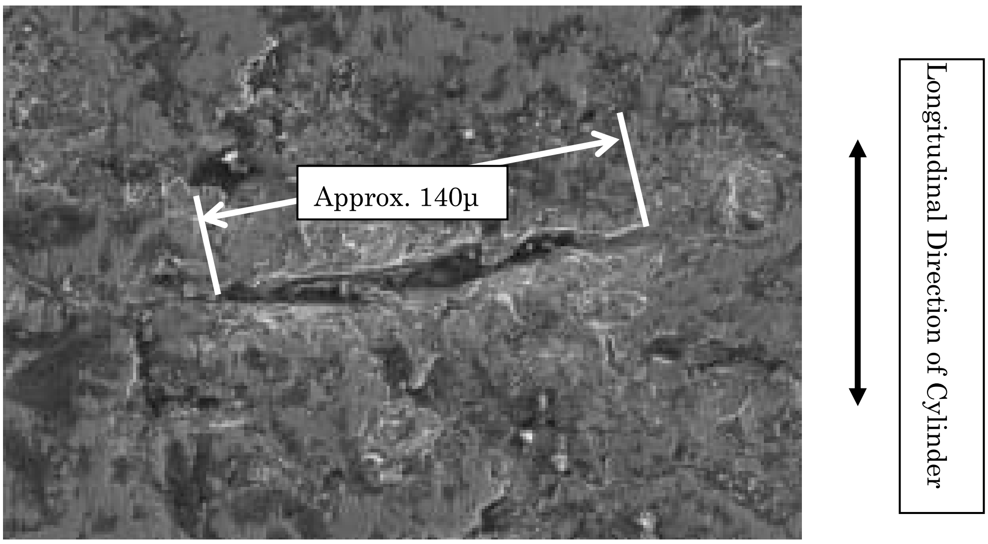


Photo 12　Surface Flaw of Cylinder



Surface Flaw of Rupture Area　　　　X 500



Surface Flaw of Cylinder Lower Portion　　X 500

Appendix 1 History of L/H MLG

DATE	EVENT	TC	CSO
Aug. 1989	Installed on JA8295 L/H when manufactured.	0	
Aug. 3, 1989	Severe brake vibration occurred during a rejected take-off (RTO) test. Brake system was carried out air-bleed.		
Aug. 4, 1989	Severe brake vibration occurred again during an RTO test on the 3rd flight test. Replaced the L/H shimmy damper and brake system was carried out air-bleed. The Anti-Skid control box etc. was replaced because there was no improvement.		
Aug. 5, 1989	Severe brake vibration again occurred during an RTO test on the 4th flight test. All brakes and the Anti-Skid control box etc. were replaced.		
Aug. 12, 1989	JA8295 was delivered to the company.		
Apr. 26, 1992	A restrictor was installed in the brake hydraulic lines of JA8295 in accordance with the manufacturer's SB (MD-80-32-246).	4,928	
Feb. 26, 1995	A special inspection was carried out after a captain's report of a suspected hard landing, and no abnormality was found.	9,994	
Dec. 20, 1995	The fuse section was inspected for cracks in accordance with the TCD-4322-95 (conforming to SB80-32A286). No cracks were found.	11,500	
Jul. 28, 1999	The MLG was removed from the JA8295 because it was approaching its overhaul time.	18,342	
Mar. 20, 2000	The MLG was overhauled at a repair station, during which the Company ordered crack inspection of the fuse section in accordance with TCD-4322-95 (conforming to SB80-32A286). No cracks were found.	18,342	0
Apr. 4, 2000	The MLG was installed on the JA8297 as the left MLG.	18,342	0
Oct. 14, 2000	The fuse section was inspected for cracks in accordance with TCD-4322-95 (conforming to SB80-32A286). No cracks were found.	19,419	1,077
Jan. 1, 2004	The MLG collapsed.	26,176	7,834

Appendix 2 Comments of the United States of America

National Transportation Safety Board

June 1, 2006

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Tokyo 100-8989
Japan

Subject: Accident Investigation Report of JAS DC-9-81 (JA8279) Left Main Landing Gear Collapse, Tokunoshima Airport, Japan, January 1, 2004

Dear Mr. Tomita:

I have received your letter of April 27, 2006, requesting comments on the final report of the subject accident. Per the provisions of Annex 13 to the Convention on International Civil Aviation, the NTSB offers the following comments to the report.

In your letter, you mentioned uncertainties regarding the use of Boeing data in the final report that was marked as "Boeing Confidential Information...". Boeing routinely marks investigation-related material as "Commercial Confidential" or "Confidential Investigative Information" not only to protect proprietary and/or sensitive Boeing data, but also to protect sensitive investigation data that has been developed by and acquired from the JARAIC, the NTSB, or other investigation sources. Such markings reduce the likelihood of Boeing accidentally or inadvertently releasing confidential investigative material, and reaffirms to the investigation agencies that Boeing is treating the shared information as confidential. Boeing provides proprietary (Commercial Confidential) data to promote technical understanding in the investigation and agrees, in this case, that the advantages of including the information in the final report outweigh the disadvantages to Boeing of releasing proprietary data to the public. The only information currently contained in the report that is proprietary is the grit blast specification. The specification listed in section 2.17.9(1) for "At repaired" is incorrect for the blast pressure. The Boeing specification calls for a blast pressure of 20-50 psi if a 3/8 to1/2 inch venturi-type nozzle is used. No blast pressure is specified for other types of nozzles. Therefore, with the correct specification included, there is no restriction on the use of proprietary data in the final report.

In section 2.16.1(2) the report states, "Slight damages were found on the cylinder surface around Origin 1" and subsequently states "no evidence of damage was observed." These statements are contradictory. Also in footnote 4, it should be noted that the Boeing process requires grit blasting prior to plating and there are specifications for grit blasting in the CMM/OHM 20-10-6 Figure 6 as detailed in section 2.17.9(1) of the report.

In section 2.16.2(4) the use of the word flaw is misleading. A certain amount of surface roughness is inevitable when performing grit blasting. This roughness, if below 125 RMS per ANSI B46.1, cannot be considered a flaw. No substantiation of a flaw is given in the report.

In section 2.17.8 it is inferred that the overhaul work was performed in accordance with the CMM. While portions of the CMM may have been included in the "Repair Standard", the overhaul did not meet the requirements of the CMM. Specifically, the cylinder was plated using titanium-cadmium (Ti-Cd), which does not conform to the type design requirements defined by the Type Certificate holder, the Boeing Company, and approved by the FAA. Further, the report states that the cylinder was grit blasted prior to plating but no specific information on the specifications was provided. The NTSB did not have the opportunity to review the maintenance records for the overhaul.

In section 2.17.9(2) the repair station grit blast pressure is higher than the pressure in the specification provided that a 3/8 to1/2 inch venturi-type nozzle was used.

The same comments as above regarding the use of the word flaw is applicable to section 3.10.3. There was no evidence of crack initiation or failure origins associated with the presence of embedded aluminum-oxide particles (see section 2.16.2(1)). In this section, the surface roughness is attributed to the grit blast procedure performed at manufacture. Evidence presented in the report indicates that the landing gear had been overhauled and also was grit blasted at that time. It is impossible to determine that the embedded aluminum-oxide particles and surface roughness was introduced during original manufacture and not at overhaul.

Section 3.10.4 states that no foreign materials were found at the fatigue fracture origins and that the cracks initiated at a surface flaw during a previous gear walk event yet no conclusive evidence of a surface flaw has been presented. It should be noted that the stress associated with a gear walk event is substantial enough to cause cracks to initiate without the presence of surface flaws.

In section 3.11 the grit blasting specification is discussed. It should again be noted that the Boeing specification does contain a blast pressure in conjunction with a nozzle size. The blast pressure used by the repair facility is higher than the Boeing specification and higher that the other landing gear repair facility.

Section 3.12 discusses the Ti-Cd plating of the accident cylinder. As stated previously, this plating process has not been approved by Boeing or the FAA for use on the MD-80 MLG cylinder. The MD-80 landing gear was designed by Boeing and manufactured by an outside entity. In this case the repair facility was also the manufacturer of the landing gear. The manufacturer of the landing gear is not in the position to approve the Ti-Cd plating process for MD-80 landing gear. That responsibility lies with the type certificate holder.

Finally, the presence of surface flaws on the cylinder caused by the grit blast procedure is cited as a contributing factor to the probable cause of this accident. As the information presented above indicates, there is no substantiation that there was a surface flaw and that it was caused by grit blasting.

The U.S. Accredited Representative team offers the following reworded probable cause based on the information presented in the report and the comments detailed above. "With respect to the collapse of the MLG cylinder, it is considered likely that the Gear Walk, which could have occurred before the restrictor plates were installed, generated large stresses on the fuse section of the cylinder surface and caused micro cracks. The micro cracks are considered to grow during normal operation and eventually lead to the fracture." All references to a surface flaw as contributory should be removed.

I appreciate the opportunity to offer comments on the draft final report. I hope the information provided is helpful. Please amend the final report or append the comments to it. Contact me if I can be of further assistance.

I look forward to receiving a copy of the final report when it is released.

Sincerely,

[redacted]

Clinton R. Crookshanks
U.S. Accredited Representative
Ph[redacted]
Fa[redacted]
E-[redacted]

cc: Mr. Bob MacIntosh, NTSB
Mrs. Dana Schulze, NTSB
Mr. William Steelhammer, Boeing

Note: The signature, phone number, etc. were blacked out by the request of the U.S. Accredited Representative