AIRCRAFT ACCIDENT INVESTIGATION REPORT

Northwest Airlines
Boeing 747-251B N637US
New Tokyo International Airport
March 1, 1994

November 29, 1996

AIRCRAFT ACCIDENT INVESTIGATION COMMISSION

MINISTRY OF TRANSPORT

JAPAN

ATTENTION

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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, text in the Japanese version are correct.

This brochure is a translation of the original report "Aircraft Accident Investigation Report on Northwest Airlines N637US,Boeing 747-251B" in Japanese language and prepared for reference purpose only with intent to be helpful to those who may wish to read the report by its English translation.

Therefore, it goes without saying that the original text in Japanese governs, should there be any discrepancy from the original on usage of word, substance of contents, or context in any part of this English version.

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AD	Airworthiness Directive
APU	Auxiliary Power Unit
CFR	Code of Federal Regulations
Cd	Cadmium
CVR	Cockpit Voice Recorder
DFDR	Digital Flight Data Recorder
EGT	Exhaust Gas Temperature
FAA	Federal Aviation Administration
FL	Flight Level
GEMM	General Engineering and Maintenance Manual
HV	Vickers Hardness
ILS	Instrument Landing System
L1(~5)	Main Deck Left-side No.1(~5)(Door)
MAC	Mean Aerodynamic Chord
MHz	Megahertz
N/A	Not Applicable
N_1	Engine Fan Speed
N_2	Core Engine Speed
NTSB	National Transportation Safety Board
R1(~5)	Main Deck Right-side No.1(~5)(Door)
SB	Srvice Bulletin
SCT	Scattered
UD	Upper Deck
UTC	Co-ordinated Universal Time

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AIRCRAFT ACCIDENT INVESTIGATION REPORT

Northwest Airlines
Boeing 747-251B N637US
New Tokyo International Airport
March 1, 1994

November 7,1996

Decision by the Aircraft Accident Investigation Commission

Chairman	Kazuyuki Takeuchi
Member	Tetsuichi Kobayashi
Member	Tsutomu Kawai
Member	Minoru Higashiguchi
Member	Yasuhiko Aihara

AIRCRAFT ACCIDENT INVESTIGATION REPORT

Northwest Airlines

Boeing 747-251B N637US

New Tokyo International Airport

March 1, 1994

1 SYNOPSIS

1.1 Summary of Accident

On March 1, 1994, Northwest Airlines' Boeing 747-251B, N637US landed as Flight 18 at New Tokyo International Airport, and while it was rolling on the runway, the forward portion of No.1 engine was detached from the wing, dangling from it and a fire broke out in the vicinity of the aft portion of the engine at about 04:38 UTC (13:38 Japan Standard Time).

There were 18 crew members and 227 passengers, totaling 245 were on board, but there were no injuries.

1.2 Summary of Aircraft Accident Investigation

1.2.1 Organization for Investigation

1.2.1.1 The Aircraft Accident Investigation Commission designated Investigator in Charge and 8 persons as investigators of the accident involved.

1.2.1.2 Technical Advisors

The Aircraft Accident Investigation Commission appointed the following 3 technical advisors for the investigation of certain technical items pertaining to the accident involved:

1 Structure-dynamic investigation and analysis of the nacelle strut

Chief of Load Research Section, Airframe Division, National Aviation and Space Technology Laboratory, Science and Technology Agency

Tetsuhiko Ueda

2 Investigation and Analysis of Upper Link Forward Fuse Pin and Fitting

Manager of Damage Mechanism Research Division, Metallic Materials Technology Laboratory, Science and Technology Agency

Satoshi Nishijima

Chief of No.1 Research Section, Environment Performance Research Division, Metallic Materials Technology Laboratory, Science and Technology Agency

Saburo Matsuoka.

Also, Research Official Etsuo Takeuchi, Environment Performance Research Division of the above mentioned laboratory participated in the said investigation and analysis.

1.2.1.3 Participation of a State concerned in the investigation and delegation of a part of the investigation.

The accredited representatives of the United States of America, a State of Registry and Manufacture, participated in the investigation of the accident involved.

Furthermore, the investigation of the maintenance system of Northwest Airlines was delegated to the NTSB of the said State in accordance with 5.1 of Annex 13 to the Convention on International Civil Aviation. The results of the investigation were made available as a special report by the NTSB on December 20, 1994, and its the excerpt was attached to this report as Appendix 2.

However, it should be noted that "4 Recommendations" in the special report was included in "5 Pertinent Information" of this report, but "5 Appendixes" was omitted.

1.2.2 Period of Investigation

March 1 ~ March 5, 1994	On-site investigation
March 2 ~ July 6, 1994	Transcription of CVR record
March 2 ~ August 31, 1994	Decoding of DFDR
March 15 ~ April 20, 1994	Detailed investigation of No.1 Engine Pylon
March 8 ~ December 20, 1994	Investigation of the maintenance system of Northwest Airlines by the NTSB

1.2.3 Public hearing from persons concerned and consultation with States concerned in accordance with 6.9 of Annex 13 to the Convention on International Civil Aviation.

1.2.3.1 Hearing from Northwest Airlines as a concerned party was taken place.

1.2.3.2 The draft final report was conferred with the accredited representatives of the United States of America who participated in the investigation as a State of Registry and Manufacture, and the Aircraft Accident Investigation Commission received the letter from him that the said State have no specific comment concerning to the draft final report on October 21,1996 (Refer Appendix 3)

2 Factual Information

2.1 History of Flight

On March 1, 1994, Northwest Airlines' Boeing 747-251B, N637US took off Hong Kong International Airport as Flight 18 with 18 crew members and 227 passengers, totaling 245 on board, at 01:30 UTC (10:30 Japan Standard Time; unless stated otherwise, all times hereinafter are in the co-ordinated universal time and followed by "UTC").

The said aircraft cruised at FL370 and FL330, approached Runway 34 of New Tokyo International Airport(hereinafter referred to as "Narita Airport") on ILS Runway 34 Instrument approach, and landed at Runway 34 at about 04:38:14 UTC.

According to the flight crew and the cabin crew, the flight between Hong Kong International Airport and Narita Airport was smooth, without encountering any turbulence. Also, the DFDR record indicated that the vertical acceleration the aircraft experienced during the flight was between 0.84g and 1.19g.

Landing of the aircraft at Narita Airport was conducted with the weight of approximately 525,000 lbs and the flap 25 unit.

The aircraft touched the center line in the vicinity of the touch-down area of Runway 34 smoothly and rolled on the runway, reducing the speed in accordance with the routine procedures.

According to the DFDR record, the touch-down speed was approximately 149 kt and the vertical acceleration at the time of touch-down was approximately 1.12 g.

According to the flight crew, after touch down, the thrust reverser was deployed at a thrust corresponding to approximately 70 % of N_1 and as soon as the captain retarded the thrust reverser lever to the idle position when the speed was reduced to approximately 90 kt, the thrust reverser lever of No.1 engine jumped up to the full reverse position.

In the CVR, at about 04:38:37 UTC, is recorded abnormal sounds, "Bang, bang" immediately after the first officer called "90 kts".

When the flight crew checked the engine instruments, it was noted that the indications of N_1 and N_2 engine speed of No.1 engine dropped to 0%, and the needle of the fuel flow indicator moved up to the vicinity of the maximum point ,but the indication of the EGT indicator was the same as that for the other engine.

The flight crew states that at this point of time, they could not grasp well what had happened, but the captain judged that No.1 engine had a trouble, showing some of the indications of flame-out, and at a speed of approximately 70 kts, he shut down No.1 engine, placing the start lever in the Cut-Off position.

At about 04:38:45 UTC, in the CVR were recorded dialogs such as "I don't know what the ……happened." and "Number one's shut down."

At about 04:39:06 UTC, when the aircraft entered Taxiway A2 from the runway, the flight crew was advised by the tower, "Your left engine is smoking." In response to this, the crew answered to the tower that they had shut down No.1 engine.

At about 04:39:42 when the aircraft made a large right turn into the parallel taxiway A, in the CVR was recorded the dialog of the flight crew; "There is a fire over there." According to the flight crew, at that time, the turf by the runway was burning, generating smoke, and they noted that smoke was drifting in the wake of the aircraft. At about this time, they received an urgent report from a flight attendant through the interphone system that there was a fire in the vicinity of No.1 engine of their aircraft.

At about 04:40:00, they stopped the aircraft on Taxiway A, and requested the tower that "We need the fire trucks out here to look at it for Northwest, please.", asking for the dispatch of the fire trucks, but the fire-fighting crew had already noticed the fire and some of them were on their way to the site.

The fire trucks arrived at the site around after 04:40 UTC, and started fire-fighting immediately.

The captain receiving the report on No.1 engine fire from the lead flight attendant who entered the cockpit at about 04:40:06 UTC, announced to the passengers through the Public Address System at about 04:40:15 UTC that they had a problem, but since it was not serious, the passengers were requested to remain seated calmly.

After confirming from the report of the lead flight attendant that the fire was still continuing, the captain instructed the lead flight attendant that "Tell your flight attendants that right now we don't plan to do anything, but tell them to start thinking about, you know about having to get out, and if we do, we'll be getting out from the right side."

After the aircraft came to a standstill, the flight crew conducted the emergency procedures of "Engine Fire/Failure Shut-down Checklist" for No.1 engine. However, no fire warning came on. So, they tested the fire warning system, but the system was not found faulty. Under such circumstances, at about04:41:22 UTC, the captain who saw the arrival of fire trucks, in order not to interfere with their activities, shut down No.2 engine.

Since the flight crew did not know that the forward portion of No.1 engine was hanging down, in contact with the ground, the captain, intending towing of the aircraft to the parking spot after the fire-fighting activities had finished, and then deplaning passengers, requested the Northwest's dispatcher to dispatch a tug.

The flight crew started the APU at about 04:45:04 UTC and shut down the remaining No.3 and No.4 engines at about 04:46:42 UTC.

After the flight crew learned the drooping of the engine from a passenger through the lead flight attendant, the flight engineer went down to the main deck and confirming through a cabin window that the forward portion of No.1 engine was drooping, in contact with the taxiway, judged that the towing of the aircraft was unable and passengers should be deplaned on Taxiway A, and requested the dispatcher to send passenger steps and buses at about 04:49:50 UTC.

At about 04:46 UTC, the fire was completely extinguished.

Around 05:01 UTC, the passenger steps and buses requested arrived, passengers and crew members deplaned using R1 and R2 doors and passenger steps, and boarded the buses which took them to the terminal building.

According to a person who saw the aircraft approaching for landing, the aircraft did not look abnormal outside, and a photo taken at that time also did not show unusual conditions around No.1 engine etc. (See Photo 7)

According to persons who watched from a point near the runway, the landing and rollout of the aircraft, the landing was normal and a fire near the aft portion of No.1 engine broke out shortly after the aircraft started the rollout succeeding the touch down .

When the fire broke out, there were a few passengers who shouted, "There is smoke (outside)." or left their seats to look outside through windows, but the instructions by flight attendants and the announcements made later by the captain and cabin attendants made them calm and quiet.

On the runway were noted scratch marks approximately 2.5 m wide and approximately 1,060 m long reaching Taxiway A2 caused by dragging of the forward portion of No.1 engine cowling along the runway, and similar marks reaching the location where the aircraft sat were also found on Taxiway A2 and Taxiway A.

The accident took place at around 04:38:UTC on a spot of the runway of Narita Airport.

2.2 Injuries to Persons

There were no injury.

2.3 Damage to Aircraft

2.3.1 Extent of Damage

Substantial

2.3.2 Damage to Parts of the Aircraft

The visual investigation conducted at the accident site, revealed that the forward fuse pin on the upper link which constituted a joint of No.1 engine nacelle strut to the wing was fractured, disengaging the upper link at the forward joint.

The diagonal brace was also disconnected at the aft joint, dangling inside the trailing edge fairing door.

Consequently, the engine was seen hanging from the mid-spar fitting which served as a fulcrum and the forward portion of the engine was dangling, contacting the ground. There were traces of fire on and around the upper portion of the nacelle strut.

The damage to parts of the aircraft were as follows: (See Photos 1~6)

① Engine and Engine Cowling

★ The lower portion of No.1 engine nose cowl and left/right fan cowl panels were damaged.

★ Left/right side cowl panels were intact.

★ The aft upper portion of the turbine exhaust sleeve was in contact with the pylon trailing edge fairing door and deformed. There were traces of fire.

★ On the upper portion of No.1 engine exhaust plug were found dents caused by contact with the trailing edge fairing door, and on the lower portion were found distortions and traces of fire. The upper attach bolt of the plug was also found fractured.

★ The visual investigation of the engine inside through the intake and the exhaust port revealed no abnormal conditions but fragments of the nose cowl were found inside the engine. Inside the exhaust port were seen traces of fire and oil discolored black.

② Aileron

★ The lower portion of the left hand outboard aileron was burnt.

③ Leading Edge Flap and Trailing Edge Flap

★ Left leading edge flaps No.2 ~ No.7 (inside) were burnt.

★ The outside portion of the left outboard trailing flap was burnt.

★ The upper portion of the left No.1 trailing edge flap track fairing was burnt.

④ Spoilers

★ The inside of the left side spoilers No.1 and No.2 were burnt.

⑤ Structural Members

★ The forward fuse pin of No.1 engine pylon upper link was fractured.

★ Its primary retainer bolt was also fractured.

★ The upper link and its fitting on the wing side were found normal.

⑥ Engine Strut

★ The forward portion of No.1 engine strut with the engine still attached dangled around the mid-spar pylon wing, contacting the ground.

★ The upper portion of the strut was burnt.

⑦ The trailing edge fairing door of No.1 engine pylon was deformed and burnt.

2.4 Other Damage

One runway center line light, three touchdown area marking lights, one runway light and three taxiway lights were damaged, and the turf on an area along the runway and a portion of the landing strip area along the taxiway was burnt.

2.5 Personnel Information

2.5.1 Flight Crew

① Captain — Male, aged 51

Airline Transport Pilot certificate	Issued on October 17, 1987
Type Rating Boeing 747	Issued on October 17, 1987
Class 1 Airman Medical Certificate	Issued on October 13, 1993, valid till April 30, 1994
Total Flight Time	25,520 hours 00 minutes
Flight Time in the Type	4,499 hours 44 minutes
Flight Time during the last 90 Days	158 hours 17 minutes
Flight Time during the last 30 Days	80 hours 09 minutes
Flight Time during the last 24 Hours	5 hours 03 minutes
Rest Period prior to the Flight	13 hours 25 minutes
Route Qualification as Captain (and the latest Renewal Date)	October 17, 1987 (February 11, 1993)
Date of the latest Emergency Training	February 19, 1994

② First Officer — Male, aged 38

Airline Transport Pilot Certificate	Issued on July 3, 1989
Type Rating Boeing 747	Issued on May 27, 1989
Class 2 Airman Medical Certificate	Issued on January 24, 1994, valid till January 31, 1995
Total Flight Time	8,429 hours 00 minutes
Flight Time in the Type	2,032 hours 02 minutes
Flight Time during the last 90 Days	123 hours 17 minutes
Flight Time during the last 30 Days	77 hours 23 minutes
Flight Time during the last 24 Hours	5 hours 03 minutes
Rest Period prior to the Flight	13 hours 25 minutes
Date of the latest Emergency Training	February 18, 1994

③ Flight Engineer — Male, aged 42

Flight Engineer Certificate	Issued on May 24, 1985

Type Rating Boeing 747	Issued on May 9, 1990
Class 2 Airman Medical Certificate	Issued on Sept 7, 1993, valid till Sept 30, 1994
Total Flight Time	10,142 hours 00 minutes
Flight Time in the Type	1,490 hours 55 minutes
Flight Time during the last 90 Days	127 hours 55 minutes
Flight Time during the last 30 Days	77 hours 23 minutes
Flight Time during the last 24 Hours	5 hours 03 minutes
Rest Period prior to the Flight	13 hours 25 minutes
Date of the latest Emergency Training	February 17, 1994

2.5.2 Cabin Crew

① Lead Flight Attendant A Female, aged 50 L1

Experience as Flight Attendant	15 years 5 months
Total Flight Time	14,850 hours
Date of the latest Emergency Training	April 19, 1993
Rest Period prior to the Flight	Not less than 24 hours

② Flight Attendant B Female, aged 31 R1

Experience as Flight Attendant	9 years 2 months
Total Flight Time	8,280 hours
Date of the latest Emergency Training	March 16, 1993
Rest Period prior to the Flight	Not less than 24 hours

③ Flight Attendant C Female, aged 25 R1

Experience as Flight Attendant	3 years 8 months
Total Flight Time	3,420 hours
Date of the latest Emergency Training	March 25, 1993
Rest Period prior to the Flight	Not less than 24 hours

④ Flight Attendant D Male, aged 33 L2

Experience as Flight Attendant	9 years 3 months
Total Flight Time	8,370 hours
Date of the latest Emergency Training	March 16, 1993
Rest Period prior to the Flight	Not less than 24 hours

⑤ Flight Attendant E Male, aged 28 R2

Experience as Flight Attendant	9 years 3 months
Total Flight Time	8,370 hours
Date of the latest Emergency Training	March 16, 1993
Rest Period prior to the Flight	Not less than 24 hours

⑥ Flight Attendant F Female, aged 28 R2

Experience as Flight Attendant	2 years 10 months

	Total Flight Time		1,890 hours
	Date of the latest Emergency Training		March 21, 1993
	Rest Period prior to the Flight		Not less than 24 hours
⑦	Flight Attendant G	Female, aged 23	L3
	Experience as Flight Attendant		2 years 5 months
	Total Flight Time		2,250 hours
	Date of the latest Emergency Training		March 21, 1993
	Rest Period prior to the Flight		Not less than 24 hours
⑧	Flight Attendant H	Female, aged 24	L3
	Experience as Flight Attendant in Years		3 years 11 months
	Total Flight Time		2,799 hours
	Date of the latest Emergency Training		March 9, 1993
	Rest Period prior to the Flight		Not less than 24 hours
⑨	Flight Attendant I	Female, aged 29	R3
	Experience as Flight Attendant in Years		4 years 11 months
	Total Flight Time		3,699 hours
	Date of the latest Emergency Training		March 21, 1993
	Rest Period prior to the Flight		Not less than 24 hours
⑩	Flight Attendant J	Female, aged 24	L4
	Experience as Flight Attendant in Years		4 years 6 months
	Total Flight Time		4,140 hours
	Date of the latest Emergency Training		March 14, 1993
	Rest Period prior to the Flight		11 hours
⑪	Flight Attendant K	Female, aged 29	L4
	Experience as Flight Attendant in Years		8 years 9 months
	Total Flight Time		8,010 hours
	Date of the latest Emergency Training		March 12, 1993
	Rest Period prior to the Flight		Not less than 24 hours
⑫	Flight Attendant L	Female, aged 27	R4
	Experience as Flight Attendant in Years		5 years 4 months
	Total Flight Time		4,860 hours
	Date of the latest Emergency Training		March 26, 1993
	Rest Period prior to the Flight		Not less than 24 hours
⑬	Flight Attendant M	Female, aged 25	L5
	Experience as Flight Attendant		3 years 8 months
	Total Flight Time		3,420 hours
	Date of the latest Emergency Training		March 20, 1993
	Rest Period prior to the Flight		Not less than 24 hours
⑭	Flight Attendant N	Female, aged 23	R5

Experience as Flight Attendant	3 years 8 months
Total Flight Time	3,420 hours
Date of the latest Emergency Training	March 20, 1993
Rest Period prior to the Flight	Not less than 24 hours

⑮ Flight Attendant P Female, aged 32 UD

Experience as Flight Attendant	12 years 7 months
Total Flight Time	11,430 hours
Date of the latest Emergency Training	March 25, 1993
Rest Period prior to the Flight	Not less than 24 hours

2.6 Aircraft Information

2.6.1 Aircraft

Type Boeing 747-251B

Serial Number 23548

Date of Manufacture May 1986

Date of Issue of Certificate of Airworthiness

May 19, 1986

Total Flight Time 31,798 hours 00 minutes

Flight Time since Periodic Check

(C Check conducted on February 20 1994)

98 hours 06 minutes

Number of Flights since Periodic Check

13

2.6.2 Engines

Type Pratt and Whitney JT9D-7R4G2

No.1	Serial Number	715178
	Date of Manufacture	May 19, 1986
	Total Operating Time	27,695 hours
	Operating Time since Periodic Check	98 hours 06 minutes
No.2	Serial Number	715177
	Date of Manufacture	May 19, 1986
	Total Operating Time	27,199 hours
	Operating Time since Periodic Check	98 hours 06 minutes
No.3	Serial Number	715190
	Date of Manufacture	June 24, 1986
	Total Operating Time	20,367 hours
	Operating Time since Periodic Check	98 hours 06 minutes
No.4	Serial Number	715187
	Date of Manufacture	March 31, 1986
	Total Operating Time	23,220 hours
	Operating Time since Periodic Check	98 hours 06 minutes

2.6.3 Weight and Balance

The weight of the aircraft at the time of the landing is estimated at approximately 525,100 lb, with its center of gravity at 26.3% MAC, both being within permissible limits (the maximum landing weight being 630,000 lbs, with the center of gravity corresponding to the weight at the time of landing 13.0%~33.0 MAC).

2.6.4 Fuel and Lubricating Oil

The fuel on board was Jet A-1, and the lubricating oil was Exxon Turbo-oil 2380 (MIL-L-23699).

2.7 Meteorological Information

The periodic aviation weather observations pertaining to the time zone of the accident provided by New Tokyo Area Aviation Weather Service Center of the Tokyo District Meteorological Observatory, the Meteorological Agency were as follows:

04:30 UTC	Wind Direction/Velocity	Variable/03 kt
	Visibility	More than 10 km
	Clouds	SCT 4,000 ft
	Temperature/Dew Point	11℃/02℃
	QNH	29.96 inHg
05:00 UTC	Wind Direction/Velocity	020°/06 kt
	Visibility	More than 10 km
	Clouds	SCT 4,000 ft
	Temperature/Dew Point	10℃/01℃
	QNH	29.96 inHg

2.8 Aids to Navigation

All navigational aids at Narita Airport and communications facilities for enroute navigation required for operation of the aircraft were in normal operating conditions during the time zone related to the operation of the aircraft.

2.9 Communications

The aircraft had maintained communications with the tower on 118.2 Mhz at the time, the communications had been good.

2.10 Airport Information

The elevation of the airport is 41 m. Runway 34 on which the aircraft landed is asphalt-concrete paved, 4,000 m long and 60 m wide, 3,250 m portion of the runway has been grooved.

2.11 Flight Recorders

The aircraft was equipped with a Teledyne (USA) Model 70-203B DFDR and a Fairchild (USA) Model A100A CVR.

2.11.1 DFDR

In the DFDR was recorded the latest operating conditions of approximately 25 hours including the record of the aircraft up to approximately 04:46:42 UTC when all engines stopped on Taxiway A of Narita Airport.

The record contains 19 numerical data and 19 circumstantial data which are made up with discrete signals.

2.11.2 CVR

In the CVR was recorded the audio information approximately 32 minute long, from 04:32:15 UTC when the aircraft was permitted to make an ILS approach to Runway 34 to approximately 05:04:17 UTC when the APU was shut down on Taxiway A of Narita Airport, stopping power supply to the CVR.

The audio sources for the 4 tracks used were as follows and the recording conditions of all of them had been good:

Track 1: Audio Control Panel at Captain's position

Track 2: Audio Control Panel at Co-pilot's position

Track 3: Cockpit Area Mike

Track 4: Audio Control Panel at Flight Engineer's position

2.12 Rescue and Fire-fighting Activities

2.12.1 Crew Activities against Aircraft Fire

2.12.1.1 Activities of Flight Crew

According to the statements of the flight crew and records of DFDR and CVR, their activities were as follows:

When the flight crew retarded the thrust reverser levers to the idle position at the speed of approximately 90 kt during the landing roll, they noted abnormal conditions of No.1 engine and shut it down.

While the aircraft was turning toward Taxiway A2, the tower advised the flight crew that smoke was coming out of one of left engines and when the aircraft just completed turning toward the parallel Taxiway A, the flight crew saw smoke drifting along the path they came rolling and at the same time, they received an emergency report on the engine fire from the cabin crew. Recognizing that a fire had broken out in the vicinity of No.1 engine, the captain stopped the aircraft on the taxiway.

Noting that the fire trucks had arrived at the site and started fire fighting activities, and the scale of the fire was not big and the fire itself was located far from the fuselage, the captain judged that there was no need for emergency evacuation and explained the situation to the passengers, requesting them to remain seated. He also instructed the cabin crew that there was no need for emergency evacuation at that time but they should be prepared for it just in case the situation should deteriorate.

The flight crew accomplished the emergency procedures of the Engine Fire/Failure Checklist for No.1 engine and shut down No.2 engine to facilitate fire-fighting activities. And all other engines were shut down later.

The fire did not expand and went out without necessitating the emergency evacuation.

Although the captain at first intended to let passengers deplane at the parking spot after the aircraft was towed to there by a tug, he let passengers and crew to deplane at the taxiway where the aircraft stopped, as he realized that towing was impossible since the forward portion of No.1 engine was dangling.

2.12.1.2 Activities of Flight Attendants

According to the flight attendants and passengers, the activities of the flight attendants and behaviors of passengers were as follows:

① Detection of Fire and Report to Captain

Those flight attendants in charge of L3, L4 and L5 doors who sat in the left side seats in the aft portion of the cabin noticed the fire soon after it broke out.

Although the flight attendants in charge of L3 and L4 tried to pass the emergency report to the captain through the interphone, this report could not be accomplished at this point in time due to simultaneous use of the system.

By the time when the aircraft left the runway and entered the taxiway, the interphone communication became normal. The lead flight attendant, (in charge of L1), receiving the report from the flight attendant in charge of L4, went to the cockpit, reported the situation to the captain and received instructions for activities to be accomplished later.

First two fire trucks arrived at the site immediately after the aircraft came to a standstill, starting fire-fighting activities at once, and the fire was extinguished in a few minutes.

② Handling of Passengers

Immediately after the outbreak of fire, some of the passengers who directed it were agitated, but the instructions by flight attendants and the explanation by the captain managed to make the cabin quiet.

Some of the passengers sitting in the left side seats of the aft portion of the cabin, noticing the fire, shouted, and some others with carry-on baggage in hand, tried to move to the right side seats, but hearing the instructions of the flight attendants, obeyed them.

Cabin announcements on the explanation of the situation by the captain and requests to passengers to remain seated, had effects to calm down passengers and they remained seated quietly.

The announcements of the captain were translated by flight attendants in charge into Japanese and Chinese, broadcast and passed on to the passengers.

2.12.2 Rescue and Fire-fighting Activities

2.12.2.1 Rescue and Fire-fighting setup at Narita Airport

The New Tokyo International Airport Public Corporation, the airport authority, is charged with the rescue and fire-fighting services at Narita Airport. It also has signed agreements with Narita City and nearby communities on the rescue and fire-fighting services and the Airport Corporation can request their assistance as required.

The Fire-fighting Section, Security Division, Office of Operation of the Airport Corporation has a command post in the east side area of the airport, a fire-fighting center where vehicles such as fire trucks are stationed and a detachment of fire trucks located on the west side of the center of the runway which is manned around the clock by fire-fighters in shifts. The setup of facilities and personnel is in compliance with Annex 14 "Aerodrome" to the Convention on International Civil Aviation, and there were 22 fire-fighters on duty at the time of the accident.

On the same day, a fire drill of the autonomous fire-fighting squad organized by Committee of Managers of Fire-fighting in Cargo Agents Building was taking place in the cargo area, and fire trucks of Fire-fighting Department of Narita city participating in it, also was engaged in the fire-fighting.

2.12.2.2 Fire-fighting Activities of Fire-fighting Organizations

At about 04:38 UTC, fire-fighters engaged in the maintenance of fire fighting equipment near their detachment, noticed a fire on the left side of a landing aircraft, informed the Command Post of the fire by radio, and they chased the aircraft with fire trucks which had been standing by.

The Command Post issued a Class 2 Dispatch Order (emergency dispatch) for all fire trucks and notifed Narita City Fire-fighting Headquarters of the fire at the same time.

At about 04:40 UTC, the fire trucks which had been chasing the aircraft, arrived at the site where the aircraft stopped and started to extinguish the fire in the aft portion of No.1 engine.

At about 04:42 UTC, all fire trucks of Airport Public Corporation arrived at the site and participated in the fire-fighting activities.

Since the fire went out at about 04:46 UTC, the fire-fighters started the cooling-down and fire-fighting of turf areas near the runway and Taxiway A2.

At about 04:49 UTC, fire trucks from Narita City arrived at the site.

At about 05:13 UTC, the cooling-down operation ended. Although Class 2 Dispatch Order was withdrawn at 05:29 UTC, a chemical fire truck and a water tank truck were kept alerted until about 09:21 UTC.

《Note》 Class 2 Dispatch: Rescue and fire-fighting trucks are to be rushed to the accident site and start rescue and fire-fighting activities immediately.

The following fire-fighting trucks were dispatched:

Airport Corporation Fire-fighting : 1 command car, 1 rescue demolish truck, 3 chemical fire-fighting trucks, 3 water tank trucks, 3 rescue wagons, 1 rescue medical equipment carrier.

Narita City Fire-fighting : 2 chemical fire-fighting trucks, 2 water tank trucks, 1 water tank and pump car, 1 rescue equipment truck, 2 rescue wagons.

2.13 Tests and Research conducted to verify Facts

2.13.1 Investigation of Aircraft

① General

It was noted that No.1 engine of the aircraft dangled with the mid-spar fitting as the fulcrum, touching the ground as the upper link which served as the attachment of the nacelle strut to the wing was disconnected at the forward joint due to the fracture of the forward fuse pin, and diagonal brace was disconnected at the aft joint as the aft fuse pin slipped out. (See Figure 3 and Photos 1, 2 and 3)

Damage due to the dragging against the ground during the landing roll and the rollout after it, was noticed on the lower portion of the engine nose cowl and both left and right fan cowl panels.

There were traces of fire on the upper portion of No.1 engine nacelle strut and the wing portion after it.

② No.1 Engine

The visual investigation of the interior of the engine through the intake and the exhaust port, did not reveal any damage, but there were many fragments of the nose cowl inside the engine. Traces of fire and oil discolored black were noticed inside the exhaust port.

The investigation of the inside of the engine through both left and right fan cowls and side cowl panels disclosed no traces of fire and no other abnormal conditions.

The fan thrust reverser of No.1 engine was found in the stow position.

③ Upper Link and Joint of No.1 Nacelle Strut

Although no abnormal conditions were found on the upper link and the fitting on the wing side, a stepped deformation of a light degree was noted on the aft pin.

The forward fuse pin was fractured into 3 parts. The center part was found attached to the rear mount bulkhead fitting and 2 other parts, separated from the upper link, were found in the strut.

The primary retainer of the fuse pin is an assembly consisting of a cap, a bolt and a nut. As the fuse pin was fractured, the bolt was fractured into 3 parts. The cap and the broken bolt were found in the strut, still attached to the fuse pin. (See Figure 4 and Photos 5 and 6)

The center part of the bolt was missing and this fragment was not found since it was a small fragment with a diameter approximately 12 mm and 40 mm long in spite of a search of an extensive area of the runway, taxiway and grassy land.

④ Diagonal Brace and Joint of No.1 Nacelle Strut

No damage was found on the diagonal strut, and the forward joint was also found intact.

The diagonal brace was found disconnected at the aft joint, and the aft portion was found in the trailing edge fairing. The aft joint fuse pin was found, inserted halfway into the brace lug. (See Fugure 5 and Photo 4)

Both primary retainer and secondary retainer were not found either in the aircraft or in its vicinity, and an extensive search of the runway, taxiway and grassy land also failed to find them.

⑤ Mid-spar Fitting and Joint of No.1 Nacelle Strut

The mid-spar fitting and its fuse pin were found intact.

⑥ Damage to No.1 Nacelle Strut, its Vicinity and other Parts (See Photo 5)

★ The side brace was fractured at the strut side joint.

★ It was noted that the return line pipe located in the reservoir tank of No.1 hydraulic system was broken, damaging the tank and resulting in the loss of all hydraulic oil. It is estimated that this damage was caused by the drooping of the forward portion of the nacelle strut. It was also found burnt.

★ The fuel feed pipe between the nacelle strut and the wing was disconnected at the joint of the wing and the strut, and the bleed air duct was also found detached at the strut side joint and damaged.

★ Three generator feed cables and one thrust control cable were broken and all of them were found burnt.

★ It was noted that the hole of the joint of the strut rear engine mount bulkhead fitting and the upper link was deformed into an oval shape in the direction toward the upper link.

★ The return filter module, the case drain module, the pressure module, and the air driven hydraulic pump located in the fairing were found burnt.

⑦ Flap

The leading edge flap was found in the extended position.

The trailing edge flap was found in the 25 unit down position.

⑧ Position of Levers and other Items in Cockpit

The position of principal levers and switches in the cockpit were as follows:

★ Flap lever	25 unit down	
★ Engine		
Thrust lever	All engines	: Idle
Thrust reverser lever	No.1 engine	: Full reverse position
	Other engines	: Idle (Full down) position
Start lever	All engines	: Cutoff
Fire extinguisher handle	No.1 engine	: Pullout (It had not been rotated)
	Other engines	: In
★ Fuel system		
Engine fuel shutoff valve	No.1 engine	: Close
	Other engines	: Open
★ Hydraulic system		
Engine driven hydraulic pump switch		
	No.1 engine	: Supply off
	Other engines	: Normal
Air driven hydarulic pump	All engines	: Off

Electric driven hydraulic pump (No.4 only)		: Guarded off
★ Pneumatic system		
Isolation valve switch	Left	: Close
	Right	: Open
Engine bleed air switch	No.1 engine	: Close
	Other engines	: Open

2.13.2 Search of Runway and its Vicinity

The fact that the center portion of the retaining bolt fractured to three pieces attaching the upper link forward fuse pin and the primary and the secondary retainers of the diagonal brace aft fuse pin were missing gave rise to the possibility that their fragments or parts might have been scattered on the runway or its vicinity.

However the investigation of the debris recovered by cleaning of the runway accomplished immediately after the occurrence of the accident, the search of the taxiway and the runway conducted at the night of the day of the accident, the search of the grassy land around the runway conducted later and the investigation of the debris recovered after the grass was moved failed to discover those parts or fragments.

2.13.3 Discovery of Retainer at Maintenance Facility where C Check was conducted

According to the investigation by the NTSB, the retainer was discovered under the following circumstances at Northwest's maintenance facility located in Minneapolis, USA where C check was accomplished:

At about 9 o'clock of March 1 (local time), one of the mechanics engaged in the maintenance found a white sack near a hand rail of the under-wing work stand in which was contained a primary retainer set and to which was tied the secondary retainer with wire.

The site of this discovery was inside No.6 hangar where C check was conducted on the aircraft, between a handrail and a wood board of the left wing work stand on which the maintenance work on No.1 engine of the aircraft was accomplished.

2.13.4 Analysis of Vertical Acceleration recorded in DFDR

After C check was completed on February 20, 1994, the aircraft flew 14 times between February 21 and March 1. The DFDR recorded approximately 25 hours consisting of a part of the 11th flight, full

12th and 13th flights and the flight between Hong Kong Airport and Narita Airport until all engines were shut down on the taxiway of Narita Airport.

The investigation of vertical acceleration during this 25 hour operation, revealed that in the DFDR was not recorded strong accelerations such as those accompanying turbulences and hard landings which could have resulted in the fracture of the upper link fuse pin.

2.14 Addition Information

2.14.1 Nacelle Strut (See Figure 6)

The nacelle strut has a box structure consisting of the spar, bulkhead, ribs, panels and stiffeners. Its upper side is attached to the lower surface of the wing and on its lower side is installed the engine.

To the wing is attached the nacelle strut with the strut upper spar and the wing front spar through the upper link, with the strut lower spar and the lower surface of the wing (rear spar) through the diagonal brace and with the outer mid-spar fitting through the mid-spar fitting, the lower surface of the wing (2 locations) and the side brace.

There is a structural fuse in the joint section of the nacelle strut and the wing, which has been designed to permit the engine and the nacelle strut to separate from the wing when the fuse breaks under a load in excess of the design load. This design is intended to prevent the aircraft from encountering the catastrophe resulting from the failure of the wing.

The fuse concept comprises 4 spots, 1 upper link forward joint pin, 1 diagonal brace aft joint pin and 2 mid-spar fitting and wing lower surface joint pins.

2.14.2 Modification to Fuse Pin

At the time of the accident, the fuse pin of the aircraft was undergoing a modification, from the bulkhead type fuse pin of high tension steel to the third generation bore type fuse pin of stainless steel with modified shape and increased strength. (See Figure 7)

Northwest Airlines was also in the process of modifying the bulkhead type to the third generation type fuse pin.

In the case of the aircraft involved, during C check in February 1994, the third generation type fuse pins were introduced in No.2 and No.3

nacelle struts, but the bulkhead type fuse pins remained in place in No.1 and No.4 nacelle struts.

2.14.3 Fuse Pin Retainer

Fuse pins are equipped with retainers for the purpose of preventing them from coming out. The bulkhead type fuse pins are provided with primary retainers and secondary retainers. The primary retainer is a set of 2 caps, 1 bolt, 1 nut and 2 washers and the secondary retainer is used to attach the C shaped bracket. (See Figure 8 and Photo 8)

On the other hand, the third generation straight bore type fuse pin has been designed in such a way that it does not require the secondary retainer. (Some third generation type fuse pins do require secondary retainer similar to second generation at certain joint locations)

In the case of the aircraft involved, since the modification on the fuse pin was accomplished only in No.2 and No.3 nacelle struts, the nacelle struts which need secondary retainers and those which do not need them were intermingled.

Inboard mid-spar third generation pins also needed secondary retainer since this was a modified aircraft.

2.14.4 Maintenance System at Northwest Airlines' Maintenance Facility

The results of investigation conducted by the NTSB on the maintenance system at the maintenance facility of the airline located at St. Paul Airport of Minneapolis were as follows:

① No.5 and No.6 hangars were used for maintenance work on Boeing 747 type aircraft around the clock in three 8-hour work sifts.

② The maintenance work in general is to be conducted in accordance with GEMM (General Engineering and Maintenance Manual) in which are specified work procedures, paper handling procedures, forms etc.

③ Maintenance work on individual aircraft is to be accomplished in accordance with the work procedures shown in the CITEXT (Centralized Interactive Text System) cards generated by a computer system called CITEXT.

④ In CITEXT cards are described maintenance items required for individual aircraft in work sequence to be followed by mechanics and inspectors. If work not specified in them is to be accomplished, a "red tag" is attached to the work area involved, and a non-routine card is used to avoid the occurrence of work errors.

2.14.5 Inspection on Diagonal Brace of No.1 Nacelle Strut

The results of investigation conducted by the NTSB on the inspection of the diagonal brace of No.1 nacelle strut are as follows:

2.14.5.1 Work Instruction

C check was conducted on the aircraft involved in February 1994 in No.6 hangar of Northwest's maintenance facility located at St. Paul Airport in Minneapolis, USA.

The inspection work of C check is diversified, but the work items related to the diagonal brace lug of No.1 nacelle strut are specified in "INSP,66,AD, #1NAC/PYL DIAG B" which follow:

1 Remove Secondary Retainer (if installed).

2 Clean Lug.

3 Accomplish Ultrasonic Crack Detection Inspection.

4 -1 Accomplish Item (6) if cracks were not detected.

4 -2 Accomplish Item(5) if cracks were detected.

5 If cracks are found, replace the lug with a modified diagonal brace.

6 Apply sealant on the lug bushing flange, and install the secondary retainer if it has been removed.

It should be noted that the removal of the primary retainer is not specified in the set of instructions.

2.14.5.2 Progress of Work

The work on the diagonal brace of the aircraft was conducted on or around February 11. Several mechanics and inspectors were involved in this work. The work progress can be roughly summarized as follows, although some statements were vague for their memories had deteriorated:

1 The rear door of the nacelle strut was opened.

2 A mechanic removed secondary retainers from the diagonal braces of No.1 and No.4 nacelle struts.

3 The same mechanic cleaned the lugs.

4 An inspector conducted the ultrasonic crack detection inspection on the lugs of the diagonal braces in accordance with the instructions shown in "INSP,66,AD,#1NAC/PYL DIAG B " but could not detect cracks.

The ultrasonic crack detection inspection on the lugs of No.1 and No.4 nacelle strut diagonal braces was conducted by the same inspector, but at this point of time, the primary retainers for No.1 and No.4 had not been installed.

5 The CITEXT card calls for the re-installation of the secondary retainers. However, it is estimated that the inspector involved wrote N/A (Not Applicable) in Item 6 erroneously when he wrote N/A in Item 5, but it was not determined why he made such an error.

6 On February 15, when another mechanic removed and installed the diagonal brace aft fuse pin in order to repair No.1 nacelle upper link bushing, the primary and secondary retainers of the fuse pin had not been installed, and he did not take actions to deal with this situation.

Furthermore, neither the "red tags" nor "non-routine cards" were issued. (Although C check card does not call for the removal of the primary retainer, its removal is allowed when there is a good reason for it, and in such a case, a non-routine card is to be issued and a red tag is to be attached to the area involved.)

7 On February 19, a mechanic discovered a white bag containing a primary retainer with a secondary retainer attached outside it dangling from the trailing edge door of No.4 nacelle. As he discovered that the primary and secondary retainers of the diagonal brace fuse pin had been removed when he checked No.4 nacelle, he installed them.

8 The trailing edge fairing door of No.1 engine nacelle strut had been closed before the retainers of the diagonal brace fuse pin of No.4 engine nacelle strut were discovered.

9 In the morning of February 20, the aircraft rolled out of No.6 hangar and the operational checks of various systems were conducted.

10 On February 21, the aircraft was returned to service.

2.14.6 CITEXT Card on Modification to Third Generation Straight Bore Type Fuse Pin

Regarding No.2 and No.3 nacelle struts, CITEXT card "ENG STRUT 3RD GENERATION FUSE PINS" was issued for the modification to the third generation straight bore type fuse pins for implementation at C check in February 1994 and the instructions No.15 and No.16 of the card call for removal and discard of the secondary retainer and primary retainer of the diagonal brace aft fuse pin and the fuse pin itself, and installation of the third generation straight bore type fuse pin.

Thus, the CITEXT card called for removal and discard of the secondary retainers of the diagonal brace aft fuse pins of No.2 and

No.3 nacelle struts, and on the other hand, regarding the diagonal brace of No.1 nacelle strut, removal and re-installation of the secondary retainer for the purpose of the inspection of the diagonal brace lug was required in the inspection described in the above mentioned para. 2.14.5.

2.14.7 Work Environments at Maintenance Facility

According to the investigation by the NTSB, No.6 hangar used for C check of the aircraft involved was used as a paint hangar formerly. Therefore, a lot of paint deposited on the flood lights of the wing dock dimmed the illumination to the wing and the lower surface of the aircraft. This situation necessitated use of portable work lights and flash lights when the maintenance work was conducted. This shows that the work environments were poor.

3 Analysis

3.1 Tests and Research for Analysis

3.1.1 Investigation and Analysis of Upper Link Forward Fuse Pin and Fitting

The metallurgical investigation and the analysis of the fractured surface of the fractured upper link forward fuse pin, and investigation of the damage to the strut rear mount bulkhead fitting which was a joint of the engine side were conducted. (See Figure 1)

1 Metallurgical Investigation of Fuse Pin

The metal micro-structure investigation and the Vickers hardness tests disclosed that the material was of the uniformly tempered martensite microstructure and the hardness was normal, that is, in compliance with the materials specification of Boeing.

2 Analysis of Fractured Surface of Fuse Pin

The investigation of the pin using the scanner type electronic microscope produced results which led to the presumption that the fuse pin was sheared to destruction by an excessive tensile load applied in the direction of the upper link.

The investigation revealed no traces of fatigue on the fractured surface and other abnormal conditions such as mechanical damage, corrosion or plating failures.

3 Investigation of Strut Rear Mount Bulkhead Fitting

The measurement of the hole of the strut rear mount bulkhead fitting for deformation disclosed that it was deformed slightly to an oval shape.

Assuming that this deformation was caused by an excessive load, based on the yield stress shown in the Boeing's materials specification and the shape and size of the fitting, the load applied can be converted into the shearing load acting on the fuse pin of 857 MPa which is in excess of the shearing load of 788 MPa deduced from the Vickers hardness measured on the fractured fuse pin.

Based on the above information, it is estimated that the fracture was caused by the application of a load exceeding the design fracture strength.

3.1.2 Structure-dynamic Investigation and Analysis of Nacelle Strut

1 The nacelle strut has a statically indeterminate structure when the

diagonal brace is functioning normally. If the aft fuse pin has moved and separated from the joint, the engine load is not applied to the diagonal brace.

Even in such a case, the load applying to the nacelle strut is redistributed to the upper link and the mid-joint, by making the structure statically determinate. The shape of the attachment to the wing is still maintained.

2 If the aft fuse pin of the diagonal brace is disconnected from the joint, the load which is applied to the upper link forward fuse pin during the ground run, becomes approximately 3.8 times greater than the load normally supported by the diagonal brace.

Thus, the downward load during the thrust reverser operation makes it critical. In addition to the load due to the reverse thrust, if the downward dynamic load of approximately 1.6 g is applied to the nacelle portion, the load reaches to the design strength.

Since the engine thrust is directed forward in the case of take-off, it is can be said that the load being applied to the upper link forward fuse pin remains below the design strength, even if engine has the maximum power.

3 According to the DFDR record, the level of the vertical acceleration amplitude for the reverser operation during landing roll at Narita Airport was as low as 0.04g or so.

However, since the DFDR record of the acceleration has the sampling period of 0.25sec, it does not necessarily mean the maximum acceleration that the aircraft experienced. Further the DFDR records only the acceleration of the aircraft in the vicinity of the center of gravity, it does not mean the acceleration at No.1 nacelle strut which is located far from the center of gravity of the aircraft.

According to Boeing, it has been confirmed that, even when the acceleration level at the center of gravity position of the aircraft is at such a low level as in the case of this accident, a downward load in excess of 1.6 g at No.1 engine nacelle strut may be experiensed due to elasticity of the wing structure, given sufficient runway roughness.

Consequently, the acceleration of No.1 nacelle strut during the landing roll of the aircraft could have been greater than 1.6 g.

4 From the deductions given in 2 and 3 , it is estimated that the upper link forward fuse pin was fractured because the load due to the thrust reverser operation and the up and down motion during the landing run exceeded the design rupture strength of the upper link forward fuse pin since the joint of the diagonal brace had been

disconnected.

3.2 Analysis

3.2.1 The flight crew had valid airman proficiency certificates and valid airman medical certificates.

3.2.2 The aircraft had a valid airworthiness certificate.

3.2.3 It is estimated that the weather at the time of the accident did not affect the development of the accident.

3.2.4 Occurrence of Accident

On the latter half of the runway were found the traces caused by rubbing of No.1 engine forward portion of the aircraft against it, and according to the flight crew, the thrust reverser lever jumped to the full reverse position when the lever was retarded to idle position after using the thrust reverser. Furthermore, a witness stated that at about this time, a fire broke out around the aft portion of No.1 engine.

Based on the above statements, it is estimated that the forward portion of No.1 engine dangled down to the ground and a fire broke out in the aft portion of No.1 nacelle strut.

3.2.5 Disengagement of Aft Joint of Diagonal Brace and Fracture of Fuse Pin at Forward Joint of Upper Link

Based on the investigation of the aircraft, it is presumed that the diagonal brace was disengaged at the aft joint, dangling it in the fairing door, and the fuse pin of the upper link forward joint was fractured.

And thus No.1 nacelle strut was supported only by 2 points of the mid-spar. This resulted in the dangling of the forward portion of the engine, contacting the ground.

3.2.6 Detachment of Aft Joint of Diagonal Brace and Missing Retainer

1 The investigation of the aircraft after the accident disclosed that the diagonal brace was detached at the aft joint and the aft portion fell in the trailing edge fairing.

On the other hand, the aft fuse pin was found inserted halfway in the brace lug.

2 During the investigation of the aircraft and the search of the

runway and its vicinity, the primary retainer fixing the above-mentioned fuse pin and the secondary retainer preventing it from dropping could not be found.

Judging from the size, the probability of its loss due to breakage or disengagement is considered remote, and it is estimated that when C check was completed, the fuse pin had been installed but the secondary retainer had not been installed.

After the accident, those primary retainer and the secondary retainer were found in Northwest's maintenance facility where C check of the aircraft had been accomplished.

From the above finding, it is considered adequate to presume that the primary retainer and the secondary retainer had not been installed in the fuse pin of the said joint when the aircraft was returned to service after C check.

3 It was confirmed by several mechanics during C check that the fuse pin had been installed. It is estimated that since the load variation applied to the fuse pin in operation and the engine nacelle tilted approximately 7 ° inward, the fuse pin which had not been fixed with retainers, started moving, dropping inside, disengaging the joint of the aft fitting of the diagonal brace and the brace.

Furthermore, in the course of the investigation after the accident, the fuse pin was found inserted halfway in the brace lug. This was caused by the fuse pin which had moved inward to such an extent that the joint of the brace was disconnected, hit the inner wall of the inner fairing door and was returned outward.

3.2.7 Investigation on Handling of Retainer of No.1 Nacelle Strut Diagonal Brace during C Check

1 Installation of Primary Retainer

C check of the aircraft was conducted between February 9 and the early morning of February 20, 1994 in No.6 hangar of Northwest's facility at St. Paul International Airport in Minneapolis, USA.

During this check, the lug of the diagonal brace was subjected to the ultrasonic crack detection inspection in accordance with the procedures, and according to the inspector who conducted this inspection, the primary retainer had then been installed. However, a mechanic stated that both the primary and secondary retainers had not been installed when a job on the upper link was conducted.

The investigation by the NTSB failed to clarify when and why the primary retainer of the fuse pin of the diagonal brace aft joint was removed and why it was not installed later.

2 Installation of Secondary Retainer

It is considered likely that the secondary retainer was not installed because the inspector who conducted the ultrasonic crack detection inspection wrote N/A erroneously in the column 6 of a CITEXT card which reads "the lug bushing flange..... install the secondary retainer if it was removed in Item 1 ."

Furthermore, the intermingling of the nacelle struts which require the installation of the secondary retainer to fix the fuse pin and those which do not require them in the same aircraft, as the result of the modification of the fuse pin into the third generation type may be considered to have contributed to the confusion.

3 Completion Check of Pylon Area

The partly poor work environment of the maintenance facilities including lighting etc. in No.6 hangar of the airline may have contributed to the failure of the completion check conducted at the final stage to detect this discrepancy.

3.2.8 Fracture of Upper Link Fuse Pin

1 Results of Investigation of Fractured Surfaces and etc. of No.1 Upper Link Fuse Pin

The results of the investigation of the fractured surfaces etc. of the fractured upper link fuse pin are as follows, and it is estimated that the said fuse pin was fractured as a load in excess of the design rupture strength was suddenly applied to it:

① There was no segregation of foreign matters, and the hardness satisfied Boeing's requirements. In other words, there was no problem in the quality of the metal.

② The fractured surface did not show any signs of fatigue etc.

③ Also from the results of the investigation of the joint hole in the upper link forward fuse pin of the strut mount bulkhead fitting, it is estimated that a load in excess of the design rupture strength of the pin was applied to the pin.

2 Fracture of Upper Link Fuse Pin by Load during Landing Roll

It is estimated based on the following reasons that while the thrust reverser was deployed during the landing roll, a load in excess of the design rupture strength was applied to the upper link fuse pin, rupturing it:

① The load to be supported by the upper link fuse pin while the diagonal brace is disconnected, is approximately 3.8 times greater than the load normally supported by the diagonal brace.

Among the loads during the ground roll, the downward load during the thrust reverser operation becomes critical.

Thus, besides the load due to the thrust reverser, the addition of the downward maneuvering load of about 1.6 g results in the fracture of the fuse pin.

② During the landing roll, the aircraft deployed the thrust reverser at a thrust of approximately 70% N_1.

It is estimated that, although the amplitude level of the vertical acceleration around the center of gravity position of the aircraft recorded in the DFDR, was as low as 0.04 g, a greater vertical acceleration was experienced at No.1 nacelle strut located at location far from the center of gravity, because the wing was of an elastic structure, that can be excited by sufficient runway roughness.

According to Boeing, it is confirmed that even when the acceleration level is as low as mentioned above, the downward load at No.1 nacelle strut position can be greater than 1.6 g.

3.2.9 Shutdown of No.1 Engine

According to the captain, during the landing run, he used the thrust reverser to reduce the speed at a thrust of approximately 70% N_1 , but when he retarded the thrust reverser to idle position as the speed decreased to about 90 kt, the thrust reverser lever of the No.1 engine jumped up to the full reverse position and the instruments for No.1 engine showed abnormal indications.

It is estimated that judging from the above-mentioned situation, the captain shut down No.1 engine promptly, thus minimizing the propagation of the fire broken outin the aft portion area of No.1nacelle strut.

The reason why the thrust reverser lever jumped up to the full reverse position, is that the thrust control cable was pulled when the forward portion of No.1 engine dangled down.

3.2.10 Fire

It is estimated that as the fuel feed pipe was disconnected from the joints at both ends when the forward portion of No.1 engine dangled down, the fuel leaked into the upper portion of the nacelle strut and the adjacent wing portion.

Furthermore, hydraulic oil leaked from the damaged reservoir tank and the return line, the leaked oil entered the turbine sleeve at a high temperature (approximately 500 ~ 600℃) ignited for the spontaneous ignition temperature of oil was 965° F (518℃) and the leaked fuel caught fire from it.

Regarding the engine fire warning devices, it is estimated that the warning devices installed doubly around the engine were not activated because the location of the fire, as mentioned in 2.3.2, were on the upper portion of the nacelle strut, trailing edge fairing section etc.

3.2.11 Fire-fighting

Fire-fighters of Narita Airport Fire Station noticed fire on the left wing of the aircraft during its landing roll, and let fire trucks chase it and extinguish the fire as soon as the aircraft came to a standstill. The fire was extinguished at about 04:46 UTC.

3.2.12 Deplaning of Passengers and Crewmembers

Although learning the outbreak of a fire, the captain stopped the aircraft on the runway, the fire was not big in scale, its location was far from the fuselage, the fire trucks had arrived promptly and started fire-fighting. So he judged that the emergency evacuation was not necessary, requested the passengers to remain seated, and instructed the flight attendants to be prepared for the emergency evacuation which may be necessitated in case the situation deteriorated.

The fire was extinguished shortly without further expansion. After the fire fighting activities were finished, the passengers and the crewmembers deplaned through passenger steps at the taxiway where the aircraft stopped.

3.3 Summary of Analysis

3.3.1 C check was accomplished on the aircraft between February 9 and February 20, 1994. During this check, it is estimated that the primary retainer fixing the aft fuse pin of the diagonal brace of No.1 nacelle strut was removed, but neither it nor the secondary retainer removed for the ultrasonic crack detection inspection were reinstalled, and this discrepancy was also overlooked at the completion check.

3.3.2 After the completion of C check, the aircraft was returned to service on February 21 and accomplished 14 flights during 9 days till March 1, including the one which ended up in the accident. It is estimated that during period the aft fuse pin of the diagonal brace which had not been fixed by retainers, moved and was separated from the diagonal brace at the joint.

3.3.3 It is estimated that when the thrust reverser was deployed during the landing roll after the aircraft had landed at Narita Airport, with the diagonal brace disconnected at the joint, the forward fuse pin of No.1 nacelle strut was fractured and the forward portion of the engine dangled with 2 mid-spar fittings as fulcrums, touching the ground.

3.3.4 It is estimated that the reason why the upper link fuse pin was fractured, was that the downward load of the vertical acceleration which results from the ordinary landing roll, in addition to the load generated by the use of the thrust reverser during the landing roll with the diagonal brace disconnected, the combined load being in excess of the design rupture strength, was applied to the fuse pin involved.

3.3.5 It is estimated that in conjunction with the dangling of the front portion of No.1 engine, the fire of hydraulic oil leaked from the broken hydraulic piping and the reservoir tank, entering the heated turbine sleeve, ignited the fuel leaked from the broken fuel system, building up a fire in the aft portion of the nacelle strut involved.

It is also estimated that the propagation of the fire was minimized as No.1 engine was promptly shut down.

4 Probable Causes

When C check of the aircraft was conducted, the retainer for the diagonal brace aft fuse pin of No.1 nacelle strut was removed and the aircraft was returned to service without reinstalling the retainer. In the course of the flights after this, the fuse pin moved, disconnecting the diagonal brace at the aft joint.

It is estimated that when the thrust reverser was deployed during the landing roll under such circumstances, the forward fuse pin of the upper link was fractured due to a load in excess of the design rupture strength, dangling the forward portion of No.1 engine and a fire on leaked oil and fuel broke out in the aft portion of the nacelle strut.

5 Pertinent Information

5.1 NTSB's Safety Recommendations to FAA and Actions taken by FAA in Response to them

NTSB conducted a special investigation for the accident involved on the maintenance system of Northwest Airlines, made available the results in a special report and, on December 1995, and urged FAA to follow 5 safety recommendations.

The text of those recommendations and FAA's response (on March 20,1995 describing actions taken with respect to them, are shown below:

5.1.1 Safety Recommendation A-94-218

Review the Northwest Airlines CITEXT system, and where practical, require modification of those sections that refer to actions, comments, or systems that are specific to particular airplanes to ensure that the maintenance action requested conforms to the maintenance action required for the specific airplane.

FAA Comment

A specific inspection is scheduled to review the contents of the CITEXT system utilized by Northwest Airlines. A comparison will be made to ensure that the maintenance manual contents are accurately reflected in the actions required for specific airplane types and changes will be made where required.

5.1.2 Safety Recommendation A-94-219

Apply human engineering principles to the evaluation of computer-generated work card system to ensure that they include all of the critical information contained in, and are consistent with, the FAA approved maintenance manuals.

FAA Comment

The FAA will issue a flight standards information bulletin directing that all avionics inspectors and principal maintenance inspectors ensure that their assigned operators who utilize computer-generated work card systems accurately reflect all critical information contained in the maintenance manual. The bulletin will also provide guidance for the proper application of human engineering principles to the evaluation of computer-generated work cards.

5.1.3 Safety Recommendation A-94-220

Inform other airlines operating in the U.S., and foreign airworthiness authorities, of the circumstances of this accident and require them to implement corrective actions, where necessary, to prevent the maintenance program deficiencies noted in this accident.

FAA Comment

The bulletin referenced in the response to Safety Recommendation A-94-219 will describe the circumstances of the accident and direct principal inspectors to inform their assigned operators to take corrective action where necessary. The FAA will request that the International Civil Aviation Organization distribute the bulletin to foreign airworthiness authorities and request that they implement corrective actions.

5.1.4 Safety Recommendation A-94-221

Access the work environments in which carriers operating under 14 Code of Federal Regulations Part 121 perform their maintenance to identify human factors-related impediments to the effective performance of maintenance and inspections, such as inadequate and unorganized parts storage during maintenance activity, and require those carriers to correct the deficiencies.

FAA Comment

The FAA conducted 19 site evaluations to determine the human factors associated with aircraft inspection and heavy maintenance by 14 CFR Part 121 operators and 14 CFR Part 145 repair stations. These evaluations focused on the inspection and repair of aging aircraft; the appraisals of the illumination level, noise, occupational safety, temperature, ventilation, work support equipment, and workspace adequacy; and the extent of worker overtime.

Almost 90 percent of the sites evaluated received an overall rating of acceptable or better.

5.1.5 Safety Recommendation A-94-222

Direct operators of Boeing 747 airplanes to paint the inside surfaces of the engine pylon fuse pins a conspicuous color such as red.

FAA Comment

The FAA will address this safety recommendation in its flight standards information bulletin in response to Safety Recommendation A-94-219. The bulletin will direct principal maintenance inspectors who have oversight responsibilities for operators who operate Boeing 747 airplanes to recommend to their operators that engine fuse pins be painted red.

Note: Boeing recommends that fuse pins should not be painted red for the following reasons:

- Some fuse pins are solid stock and do not have inside diameters.
- At some joint locations, the inside diameter of the pin cannot be viewed from the end due to obstruction of the side fairing.
- These fuse pins are manufactured from 15-SPH corrosion resistant steel and require only a very light special protecting film coated to the surface. Paint is not acceptable.
- The inside surface is required to be inspectable at specific line checks. It is impractical to remove any paint each time without removing the pin, which requires engine removal.

5.2 NTSB's Safety Recommendations to Northwest Airlines and Actions taken by Northwest Airlines in Response to them

Based on the results of a special investigation conducted on Northwest Airlines, the NTSB issued 4 safety recommendations to them on December 20, 1994.

The text of these safety recommendations and the actions by the Northwest Airlines in response to them reported to the NTSB (on April 28, 1995) are shown below:

5.2.1 Safety Recommendation A-94-223

Review the CITEXT system and where necessary, require the modification of sections that refer to actions, components or systems that are specific to particular airplanes to ensure that the maintenenace action requested conforms to the maintenance action required for the specific airplane.

Northwest Comment

Northwest has reviewed and changed the control processes and work procedures directly related to the pylon failure. Additional actions include:

★ Produced text changes to enhance the exactness and applicability of the approximately 10,000 existing pages of B747 Centralized Interactive Text (CITEXT) aircraft maintenance procedures.

★ Initiated a maintenance inspector review to each new or revised 747 CITEXT procedure to ensure necessary cautions and warnings are contained therein and that the procedures match aircraft specific configurations, maintenance manual specifications and current Northwest conformity requirements.

★ Designated a CITEXT expert in the B747 hangars to help identify and correct errors or procedural problems on an ongoing basis.

5.2.2 Safety Recommendation A-94-224

Apply human factors engineering principles to the evaluation of the CITEXT system and implement revisions, as necessary, to ensure that the computer generated work cards are consistent with the material contained in the FAA approved maintenance manuals and that the specified work or inspection requirements are clearly stated.

Northwest Comment

★ Maintenance Human Factor initiatives started with the hosting of a June 1994 internal planning conference with direction from industry and academic leaders in the human factors area. As a result of this effort, Technical Operations has formed Human Factors Steering and Planning Committees, creating a top down commitment to a major cultural change.

★ Initiated the use of a Human Factors Work Card Evaluation Check List produced by Dr. Colin Drury of State University of New York at Buffalo.

The checklist and instruction on its use were provided to (43) B747 Technical Operations maintenance personnel in December, 1994. Analysis of the checklist data will provide a basis to improve work card formats and content.

★ Committed $3 million toward a new card authoring system. This system produces cards containing both text and graphics in a simplified format.

The plan is to implement the new cards on a 747-400 check in May of this year.

★ Initiated the development of a behavioral survey with the assistance of Dr. Bob Helmreich, University of Texas. This survey will be initiated in March, 1995 to provide a baseline for attitude toward work environment in the further development of Human Factors Training.

★ Implemented a Boeing Maintenance Error Decision Aid (MEDA) which identifies causes of maintenance error by providing information, from involved technicians, to form a cause/effect solution.

5.2.3 Safety Recommendation A-94-225

Review the maintenance training curricula for mechanics and inspectors to ensure that all critical airline maintenance policies and procedures are addressed during initial and recurrent training, and, in cases in which they are found deficient, incorporate such maintenance policies in the curricula.

Northwest Comment

★ Technical Training has confirmed that both initial and recurrent mechanic and inspector courses contain material addressing critical maintenance policies and procedures.

★ Further, Maintenance Training developed and implemented a Tailored Forms Management Course. This course and a special Red Tag User Course have been presented to more than 600 hangar personnel by June 1, 1995.

The actions taken exceed the recommended review and further strengthen the control of our key processes and procedures.

5.2.4 Safety Recommendation A-94-226

Review the training records of personnel engaged in the maintenance and inspection of air carrier aircraft to ensure that such personnel have received the formal training required under 14 Code of Federal Regulations 121.375.

Northwest Comment

A review of the training records of all maintenance personnel involved in the pylon failure was completed in March 1994. A review of all maintenance personnel to determine adequacy per CFR 14 121.375 is underway with expected completion by July 1995.

Figure 1 Ground Track of The Aircraft

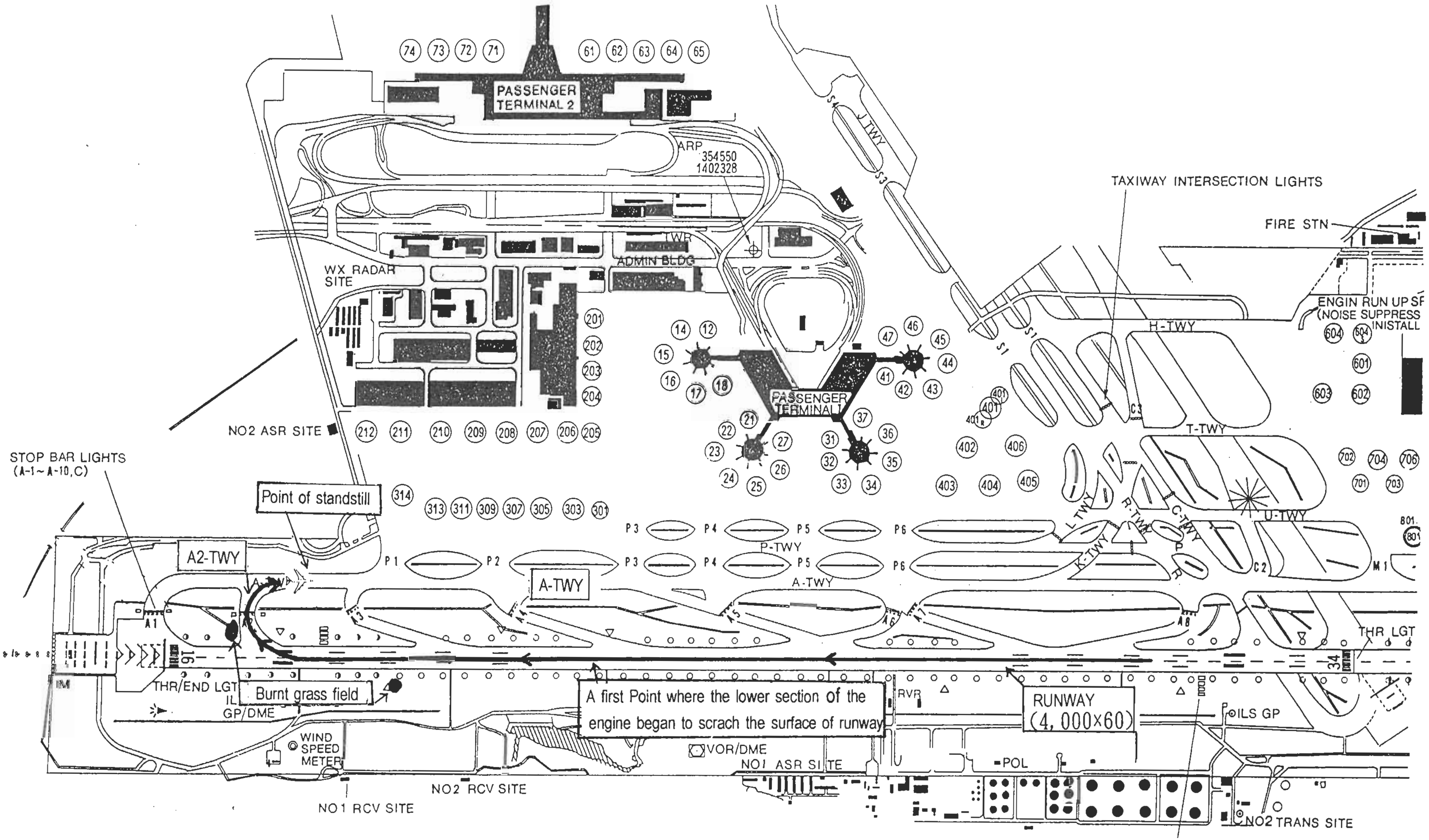


Figure 2 Three View Drawing of Boeing 747−251B Type Aircraft

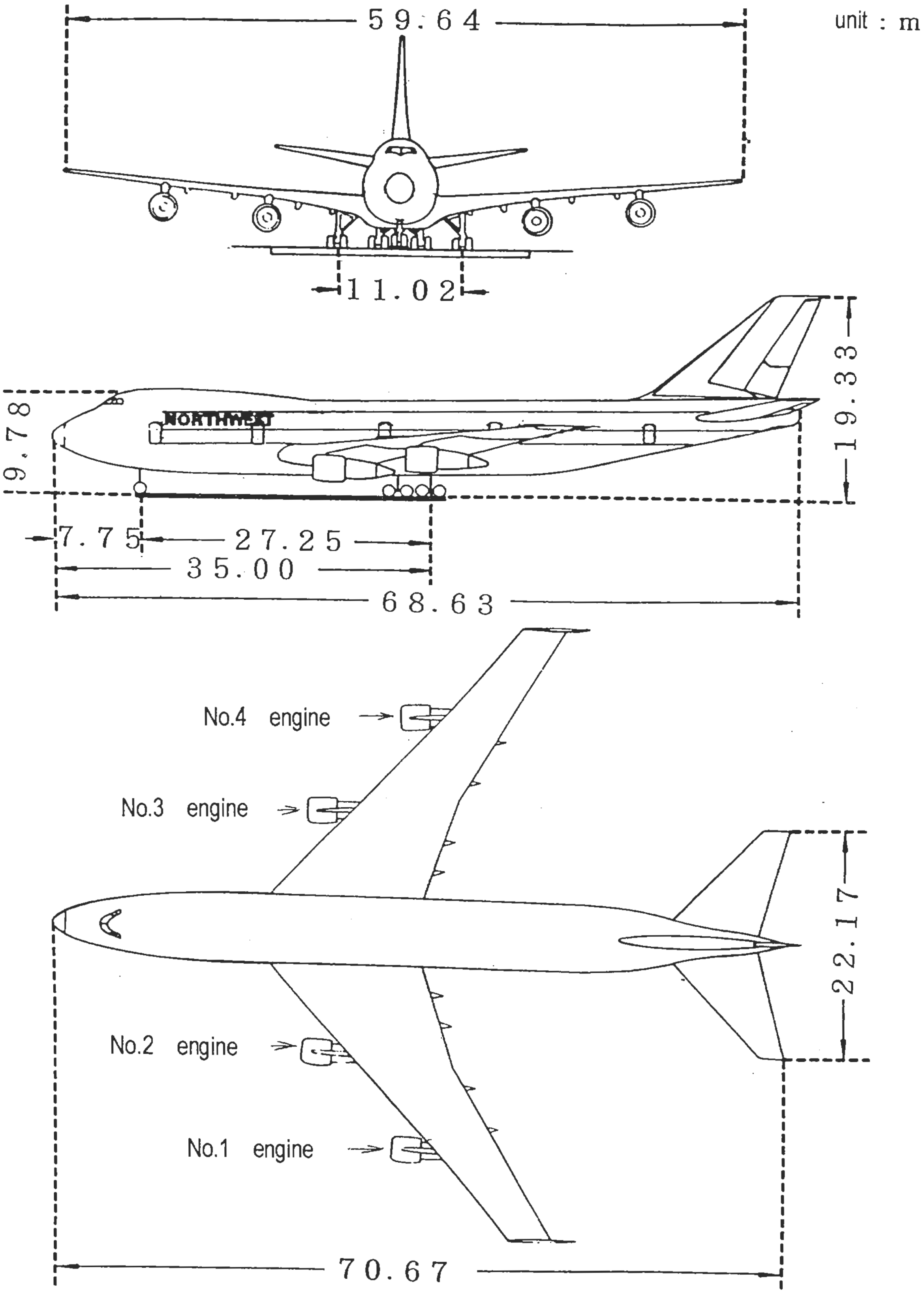


Figure 3 Schematic of No.1 Engine Nacelle Strut

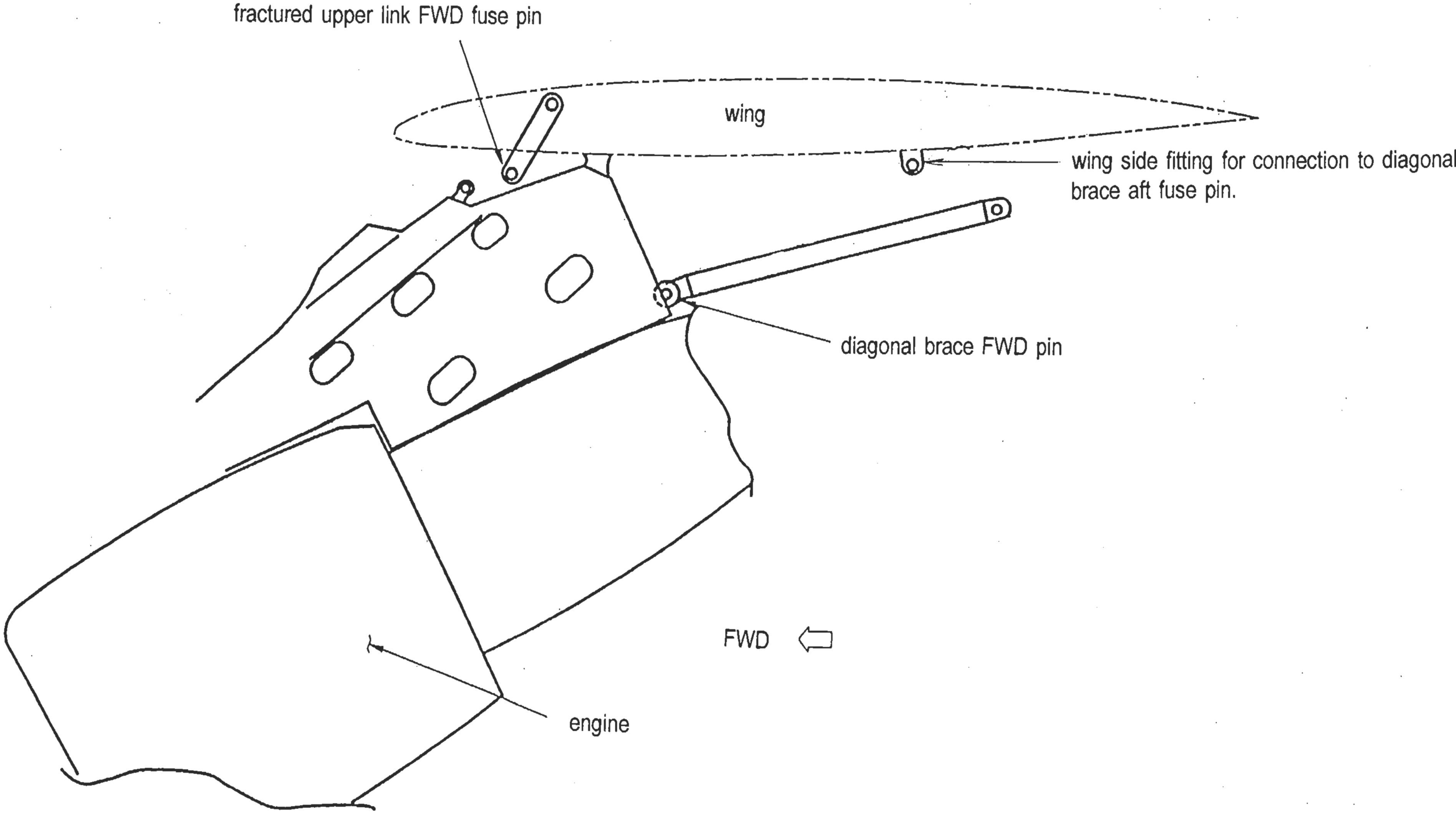


Figure 4 Cross–section of Upper Link Forward Fuse Pin

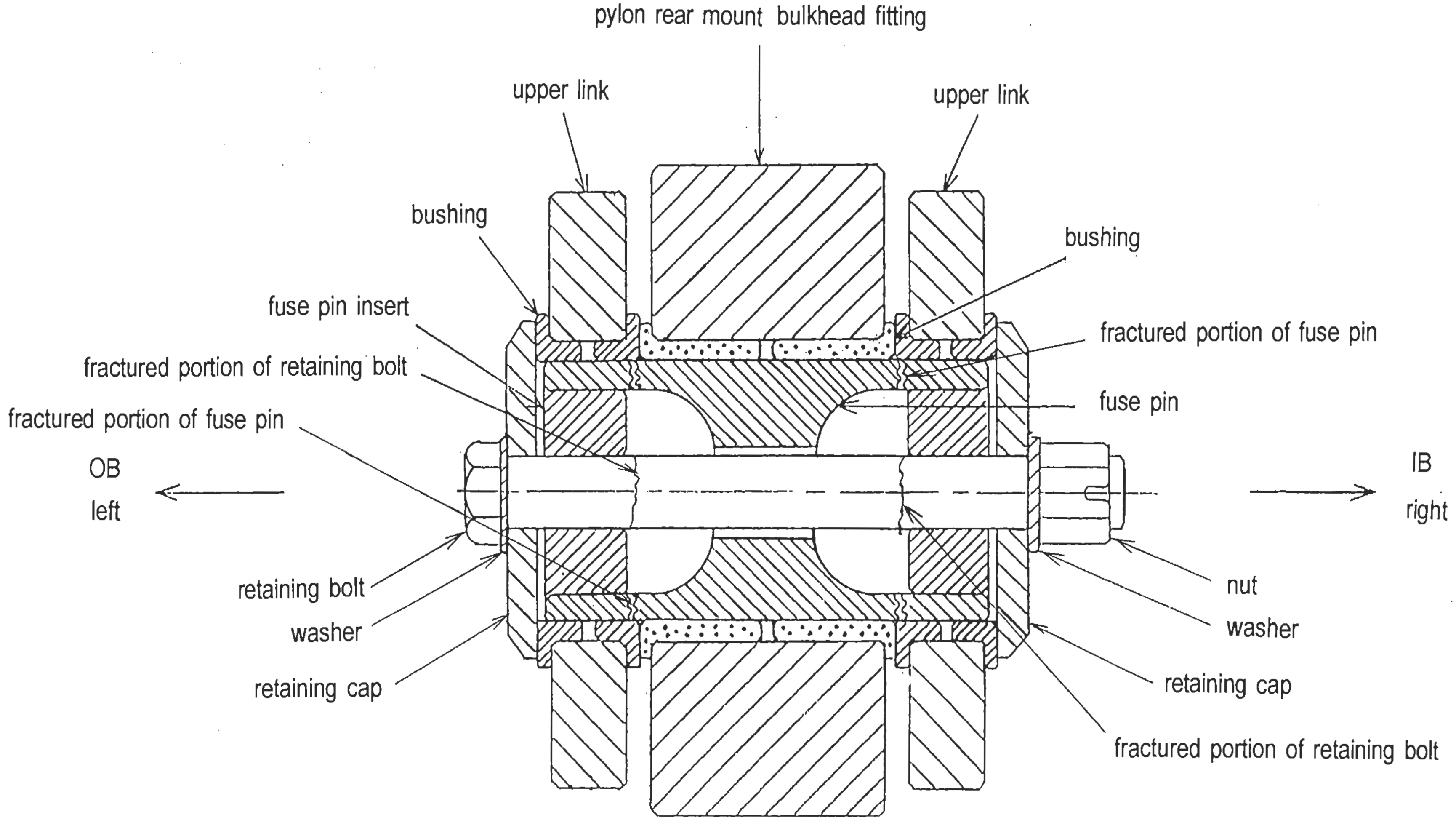


Figure 5 Sequence of Slipping of Diagonal Brace Aft Fuse Pin

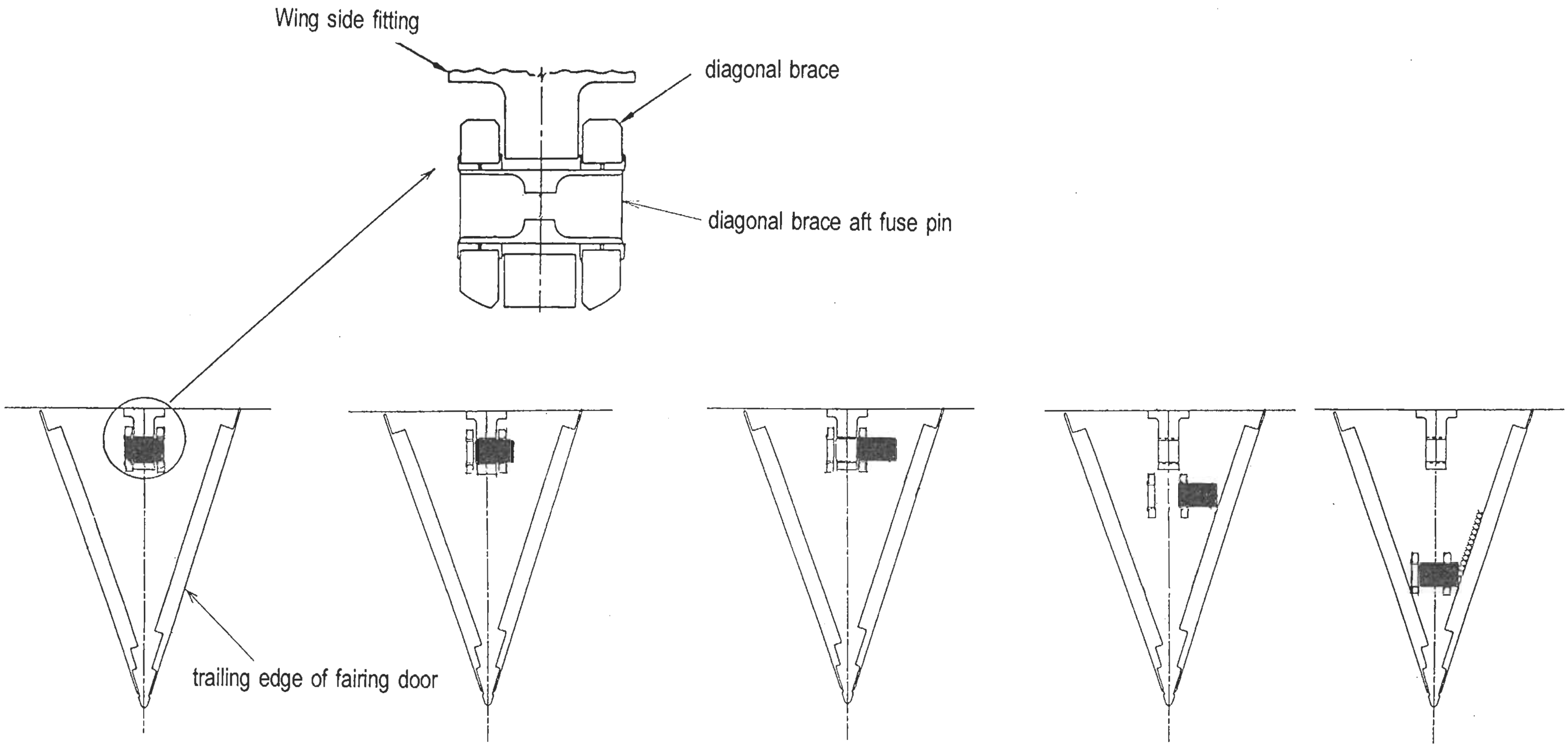
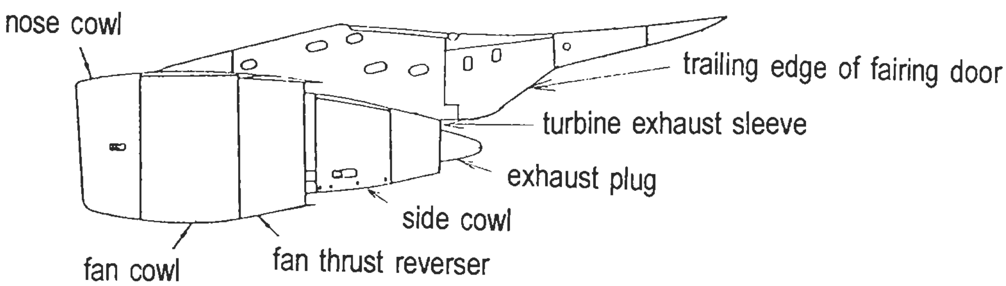


Figure 6- 1 Schematic of No.1 Engine Nacelle Strut



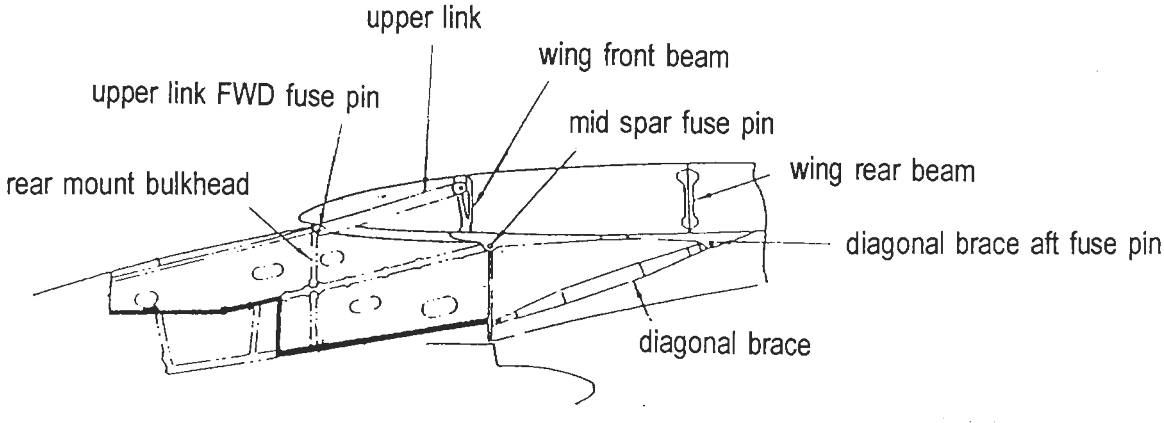


Figure 6-2 Schematic of No.1 Engine Nacelle Strut

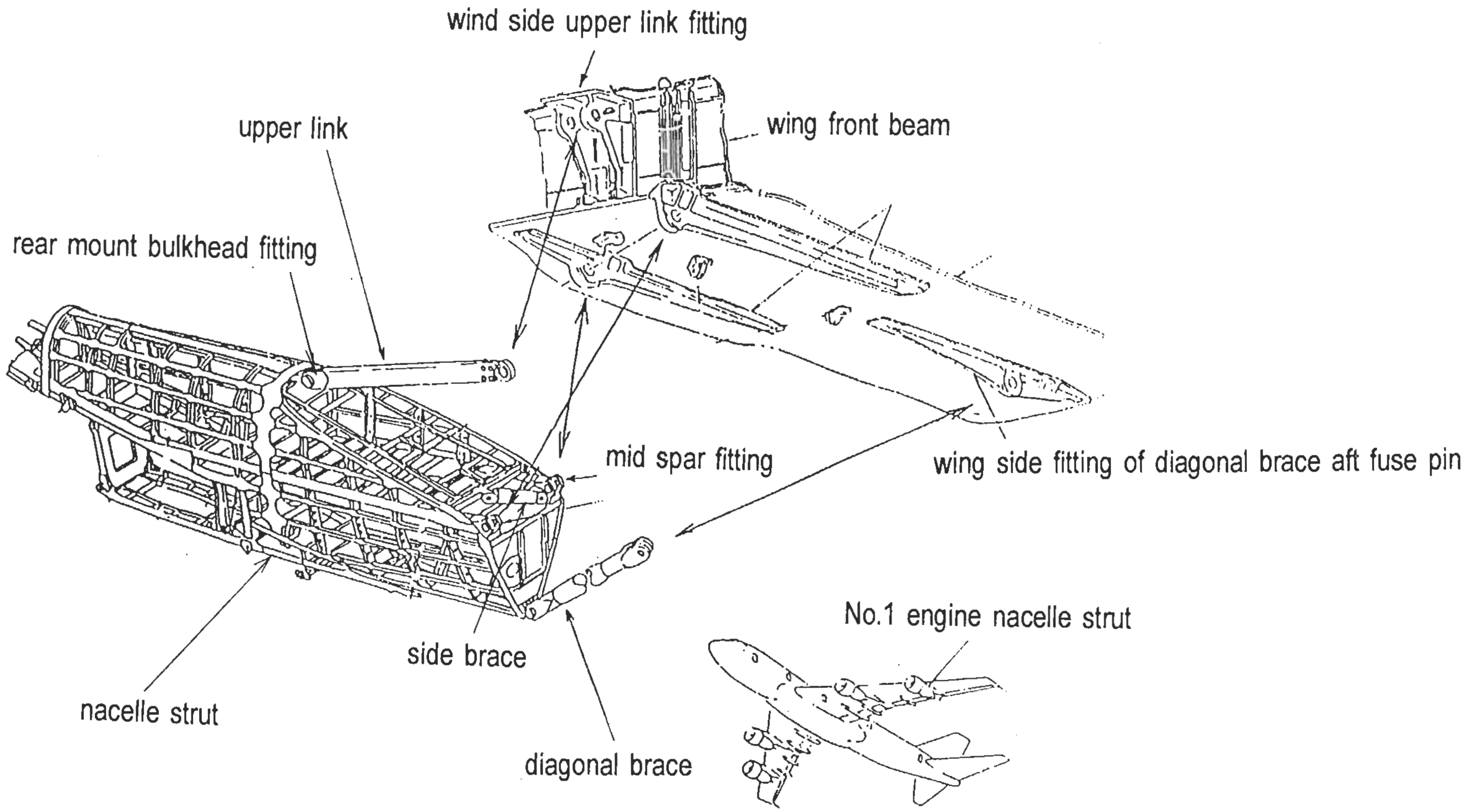
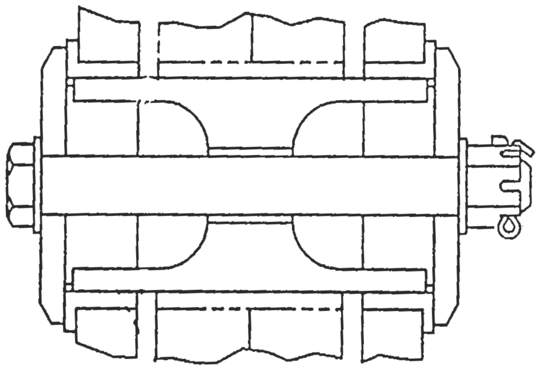


Figure 7 Shapes of Fuse Pins

bulkhead fuse pin



3rd generation straight bore fuse pin

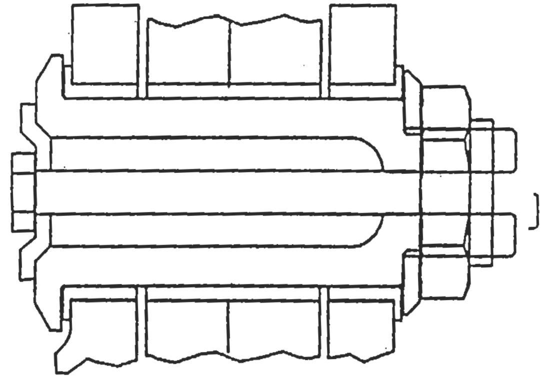


Figure 8 Schematic of Secondary Retainer of Diagonal Brace Aft Fuse Pin

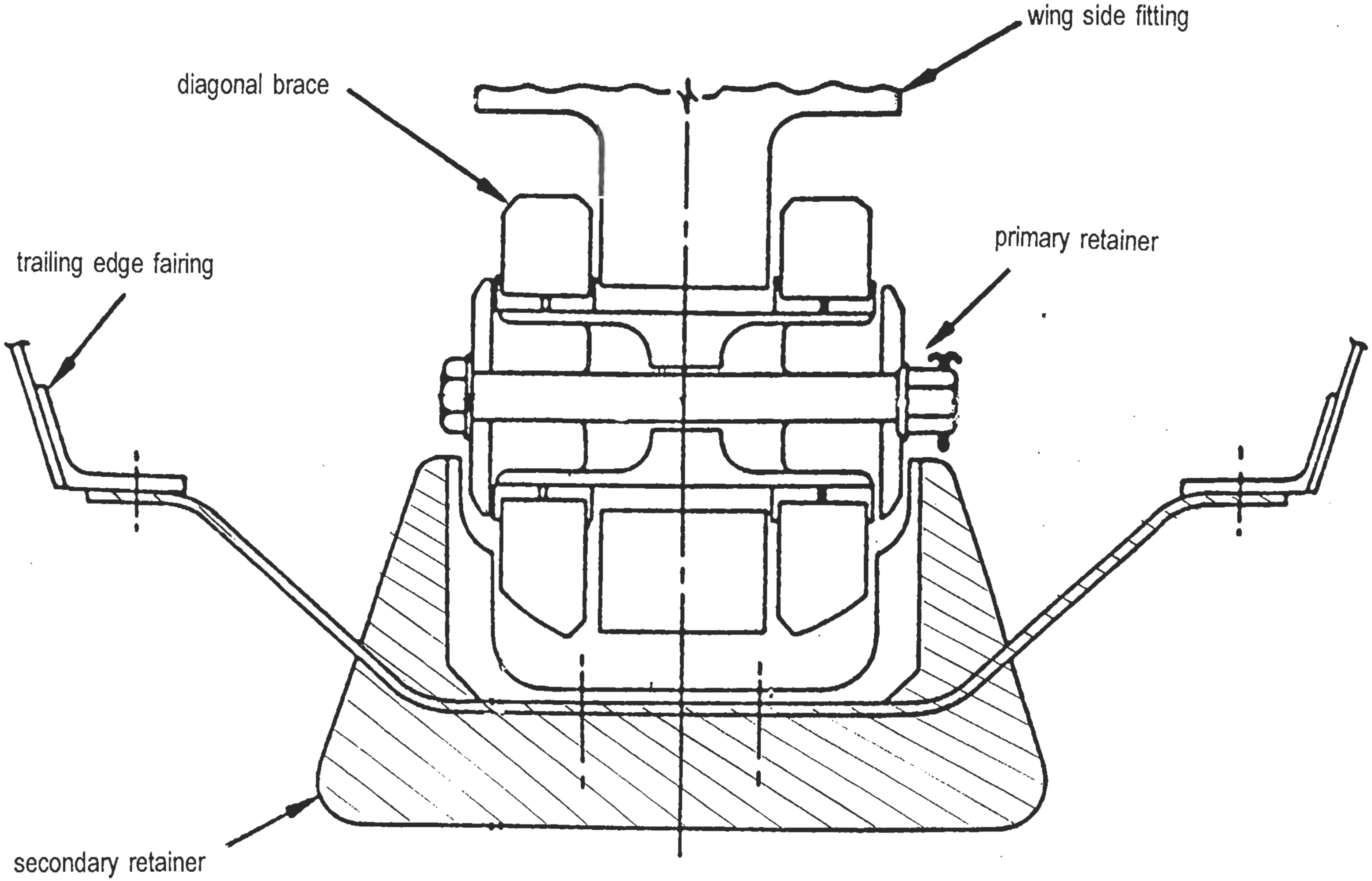


Photo.1 The Aircraft involved in The Accident

Photo.2 No.1 Engine of The Aircraft involved

Photo.3 Upper Portion of No.1 Nacelle Strut (Separated)

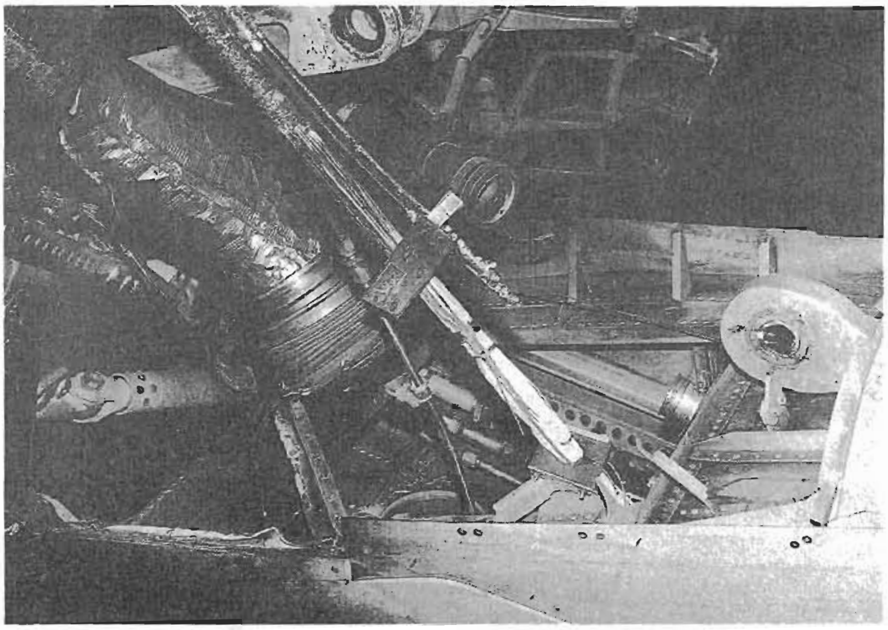


Photo.4 Aft Fuse Pin and Aft Portion of No.1 Nacelle Strut Diagonal Brace

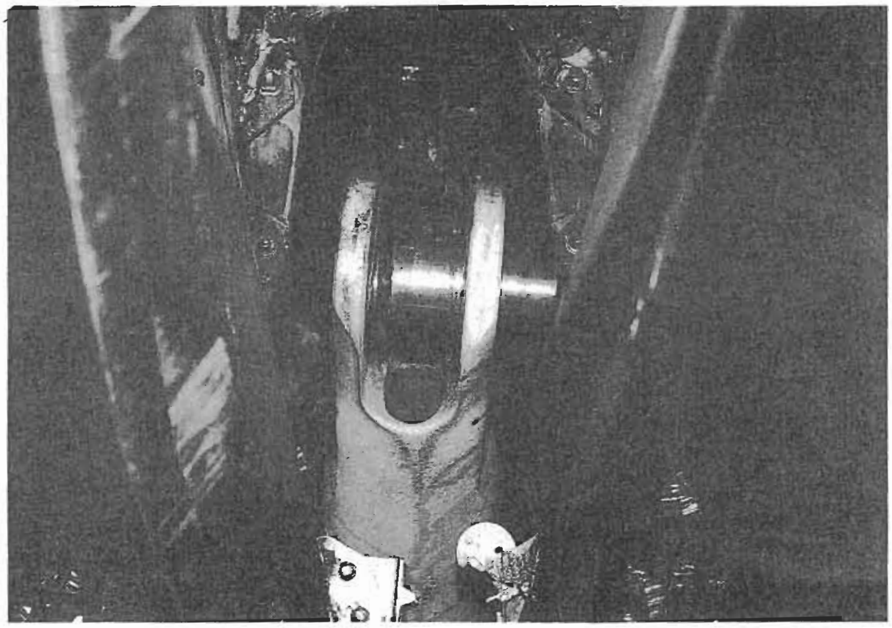


Photo.5 Burnt No.1 Nacelle Strut Trailing Edge Fairing

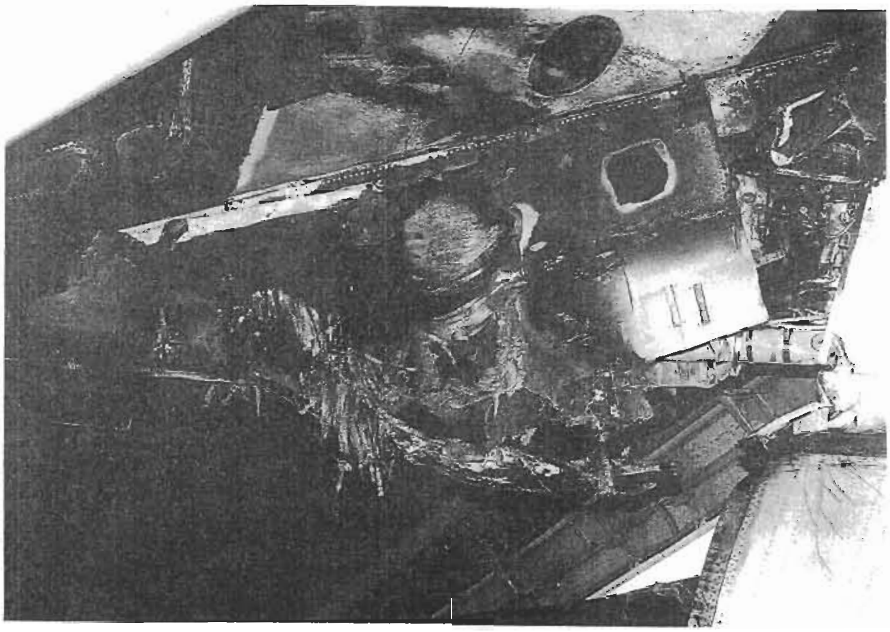


Photo.6 Fractured Upper Link Forward Fuse Pin

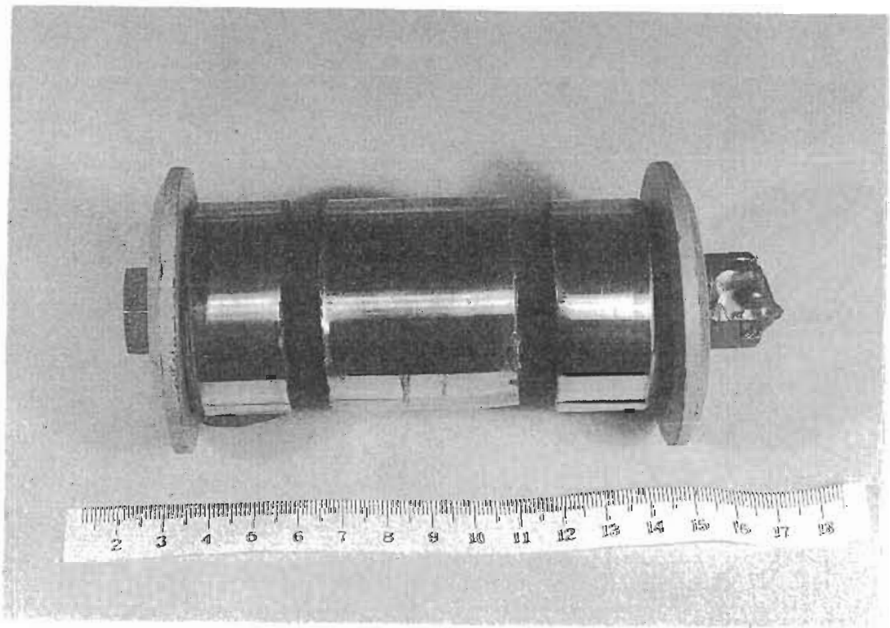
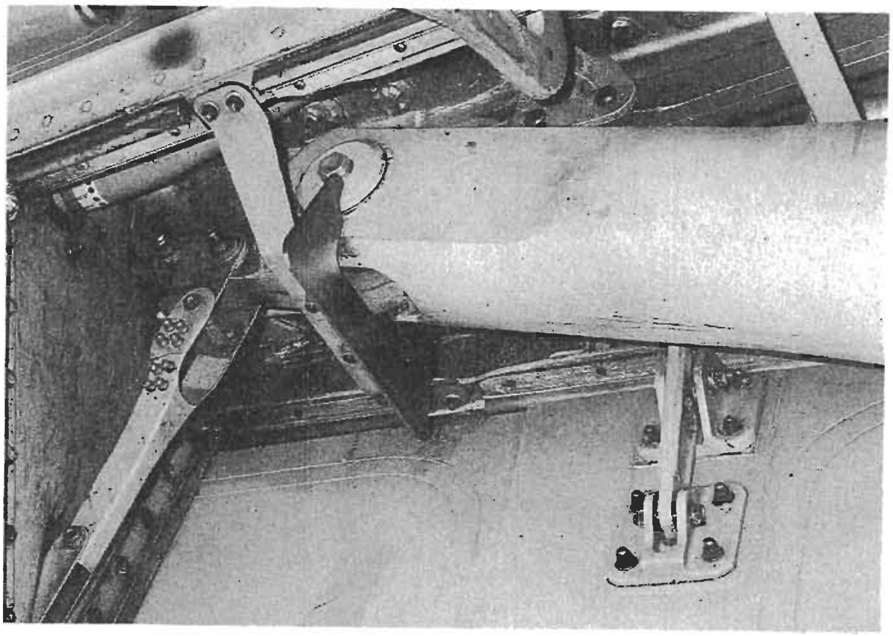


Photo.7 The Aircraft involved approaching New Tokyo International Airport

Photo.8 Secondary Retainer



Appendix 1 Investigation and Analysis of Upper Link Forward Fuse Pin and Fitting

Appendix 1 Investigation and Analysis of Upper Link Forward Fuse Pin and Fitting

A metallurgical investigation of the fractured upper link forward fuse pin, an analysis of the fractured surface and an investigation on the damaged conditions of the strut rear mount bulkhead fitting which is the joint on the engine strut side were conducted at the Metallic Materials Technology Laboratory of Science and Technology Agency

The results of the investigation were described below:

1 The fuse pin is a pillar with the total length of approximately 82 mm and the diameter of approximately 48 mm, with Cr-plated outside and Cd-plated inside, of tempered steel. Portions approximately 30 mm from both ends are of a cylindrical shape, approximately 5 mm thick, the center portion approximately 42mm are fitted into the bulkhead and both left and right ends approximately 20 mm long are fitted into the upper link forward fork. The fuse pin had been broken into 3 fragments.

2 Taking samples 1 each from both ends of the fractured pin, an investigation of micro-structure and a Vickers hardness test (HV 20) of the cross-section of the pin were conducted. They disclosed that the texture was of uniform tempered marten-site, with the hardness complies with Boeing's materials specification.

3 4 fractured surfaces of 2 pairs of samples were numbered 1 ~ 4 from the outboard side, and locations on each surface were designated by angles measured clockwise looking from the outboard, with the rearward direction of the upper link axis as the datum line.

First of all, the pair of the fractured surfaces 1－2, and the pair of 3－4 were found matching well and no significant differences between the pairs of fractured surfaces 1－2, and 3－4 were noted.

On each fractured surface were seen within the ranges of approximately ± 60° of 0° and 180° as the datum lines, elongated dimples typical of the shearing rupture were found. The direction of this shearing force was in agreement with the direction of the axial tensile force of the upper link.

Within the ranges of approximately ± 30° of 90° and 270° as the datum lines, the length of the dimples became shorter, and the co-axial dimples typical of the tensile rupture were noted partially.

In a portion around 270° line, the direction of the dimples was reversed.

Traces of fatigue and anomalies such as damage to the material, corrosion, poor workmanship of plating were not found.

4 From the above finding and the results of measurements of the deformation of the pin, it is estimated that due to an excessive tensile load applied in the direction of the upper link axis, first of all, a shearing rupture took place in the direction of 0° and 180°, it shifted to a bending rupture in the vicinity of 90° and 270°, and at the vicinity of 270° of the fractured portion, it ruptured under a bending load.

5 The strut rear mount bulkhead fitting made of aluminum alloy is designed to hold the pin through a bushing made of beryllium-copper alloy. The hole into which the bushing of the fitting is inserted, has a diameter of approximately 54 mm and is approximately 38 mm long and the thickness of the wall which supports the load is approximately 37 mm. The measurement of the deformation of the hole disclosed that the hole had been slightly deformed into an oval shape, with the inner diameter in the 90° ~ 270° direction being approximately 0.4 ~ 0.8 mm greater than that in 0° ~ 180° direction.

Assuming that this deformation was caused by an excessive load, it can be deduced to approximately 1003 kN from the yield stress of Boeing materials specification and the dimensions of the fitting. When this load is converted to the shearing load applied to the pin, it becomes 857 MPa which exceeds the shearing strength of 788 MPa calculated from the tensile strength of 1365 MPa obtained from the Vickers hardness measured on the fractured fuse pin using the Mises equation (shearing stress τ = tensile stress $\sigma / \sqrt{3}$)and it also exceeds the shearing strength of the fuse pin calculated using the Mises equation from the value of the tensile strength given in Boeing materials specification.

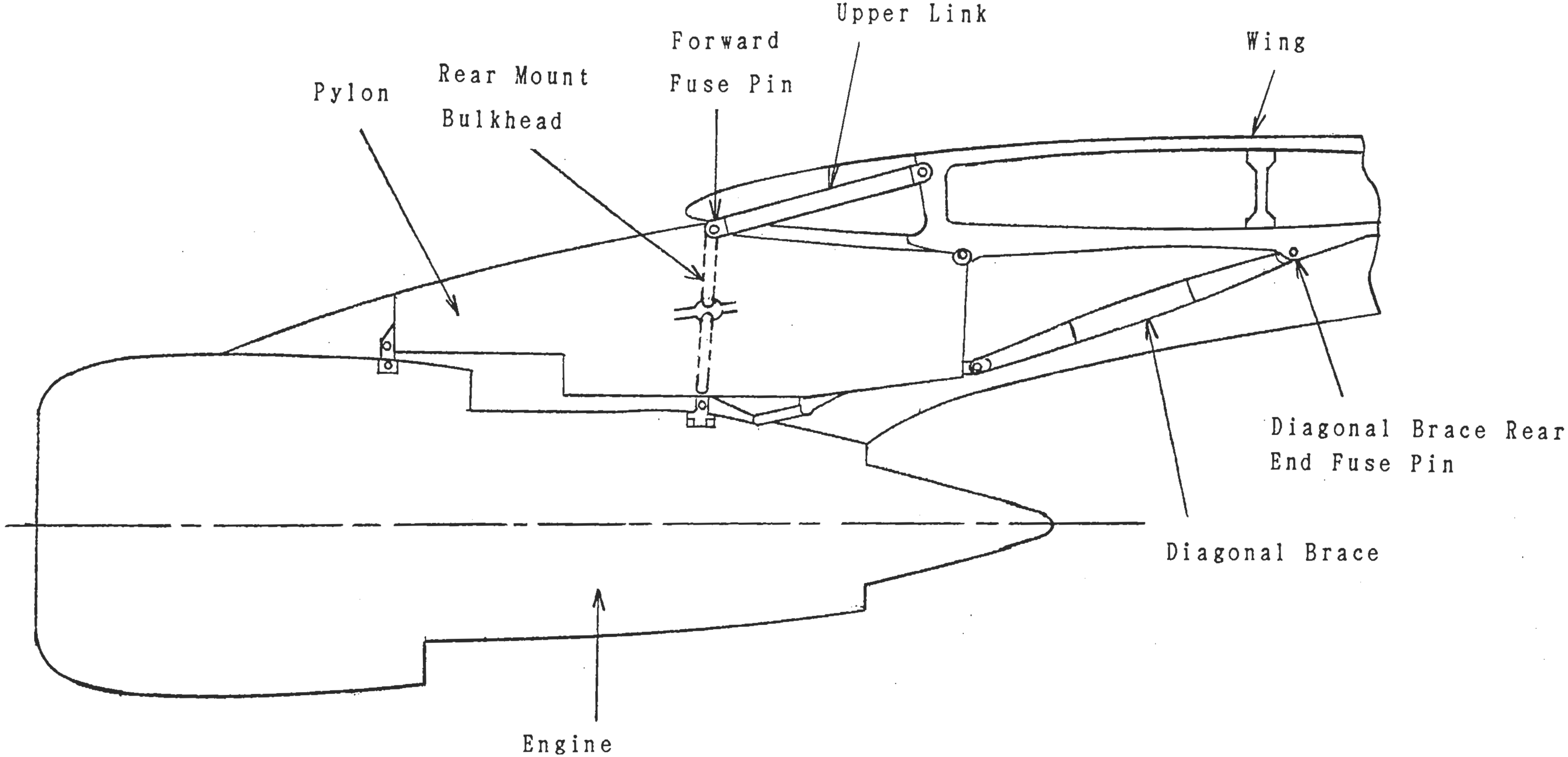


Fig.1 Schematic of Engine Strut Attachment Structure

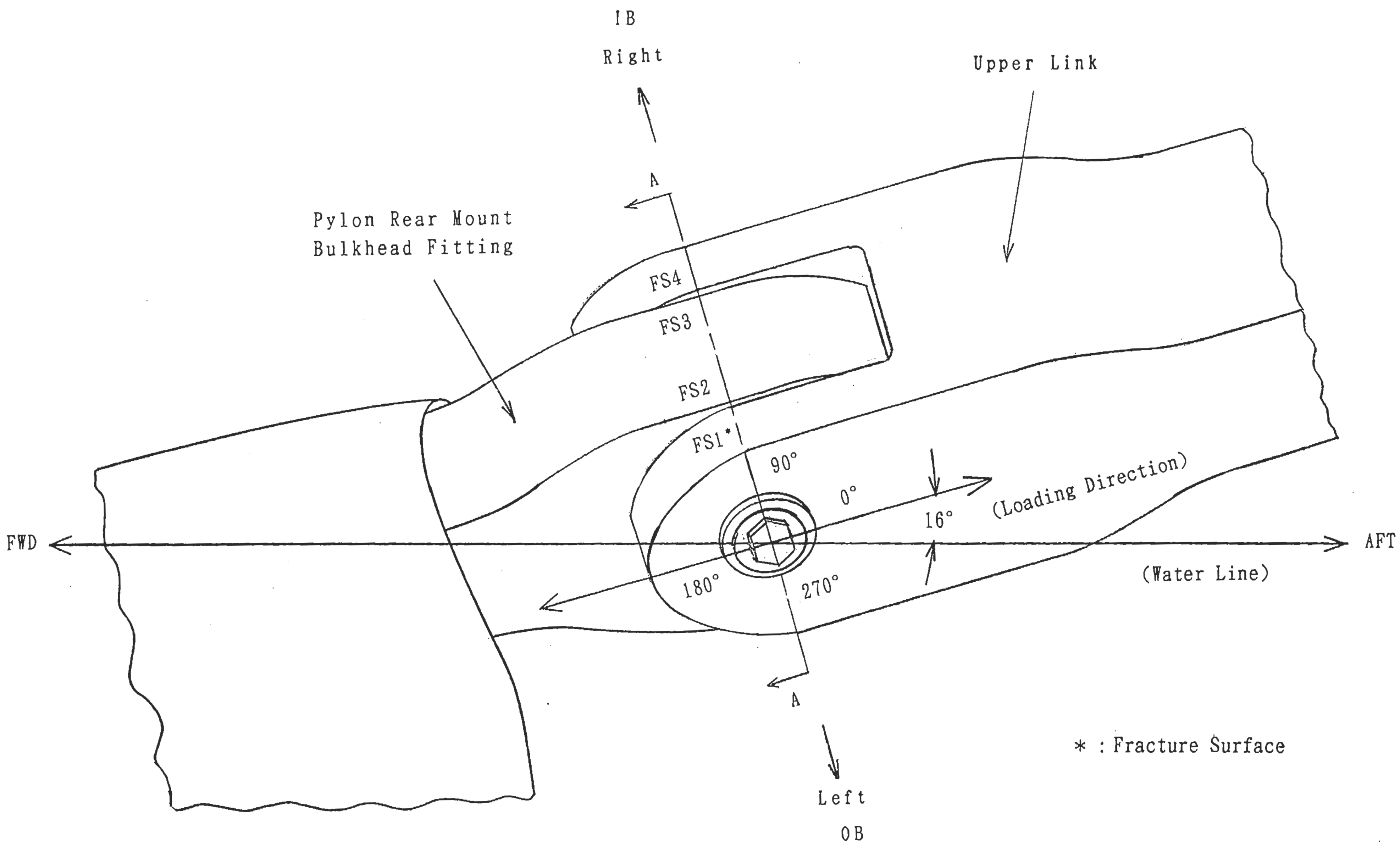


Fig.2 Schematic of Upper Link FWD Fuse Pin Attachment Device

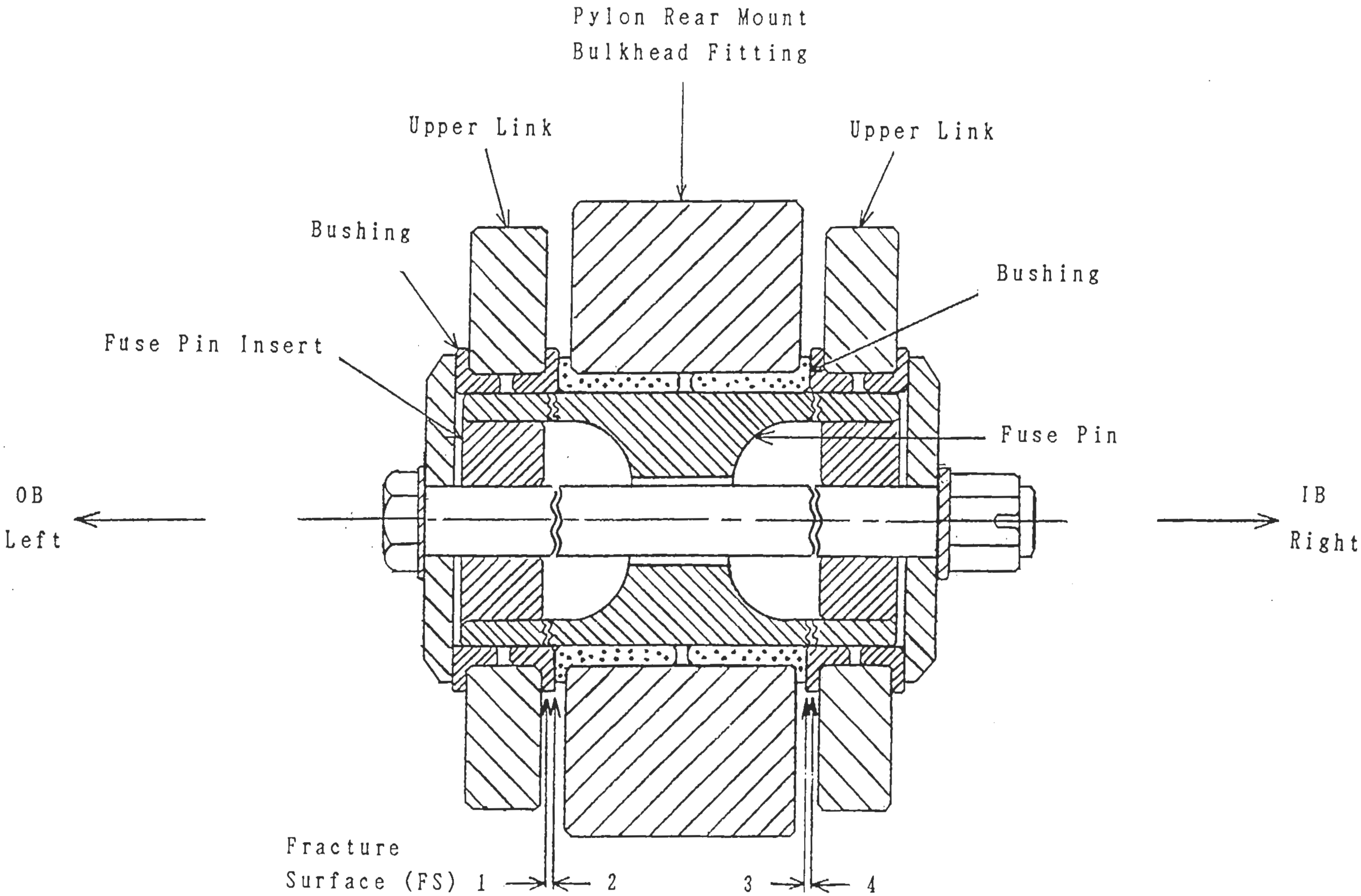


Fig.3 A–A Section of Upper Link FWD Fuse Pin Attachmet Device and Location of Fracture

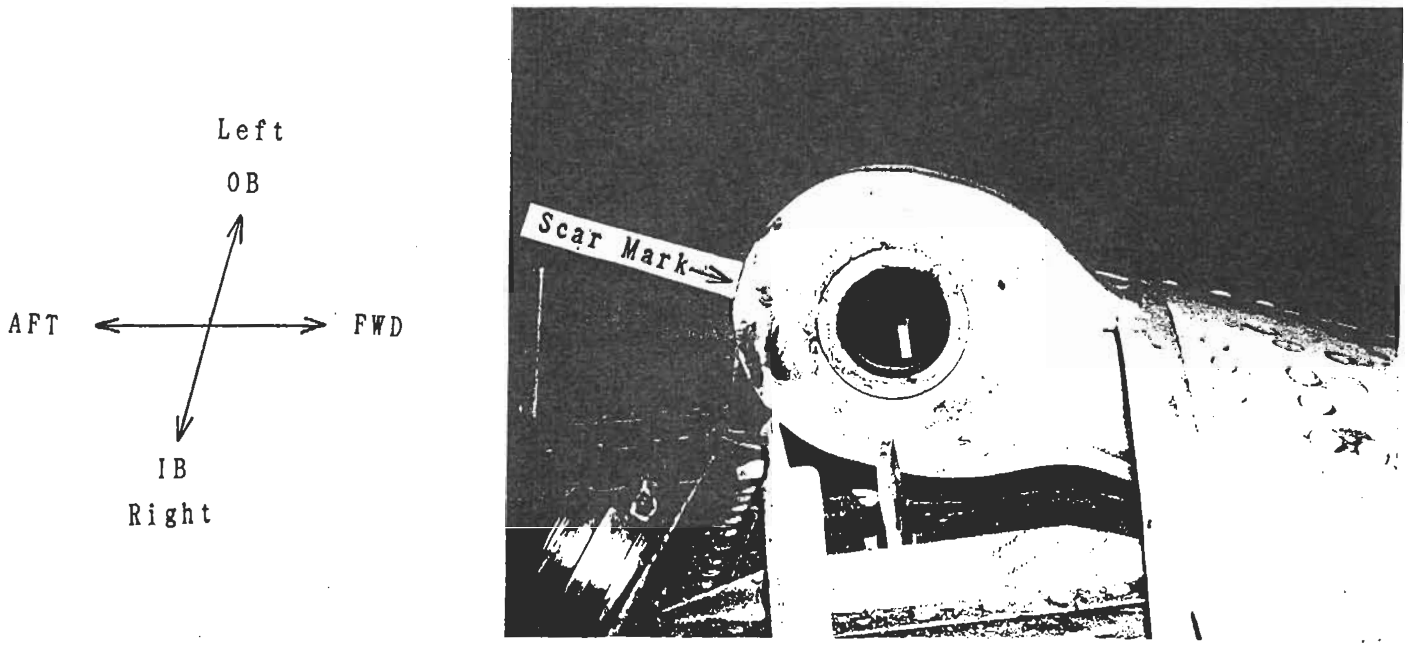
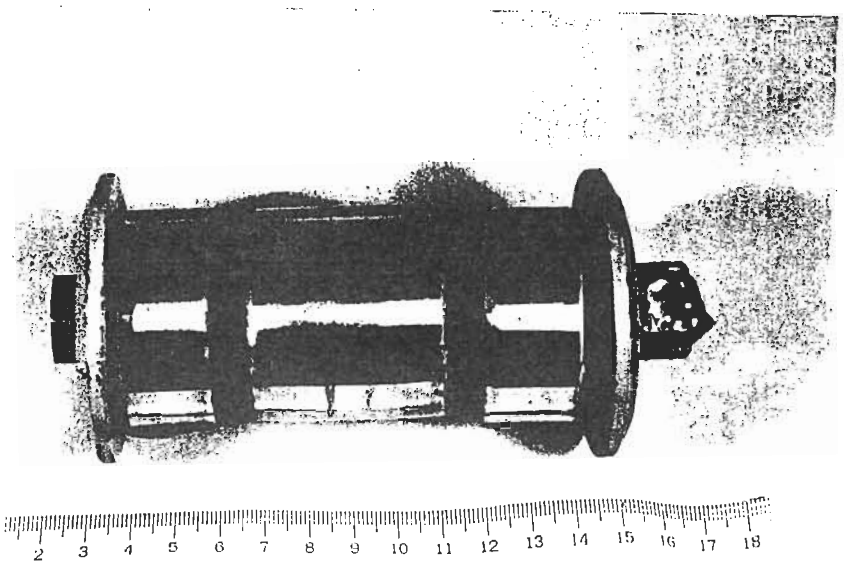
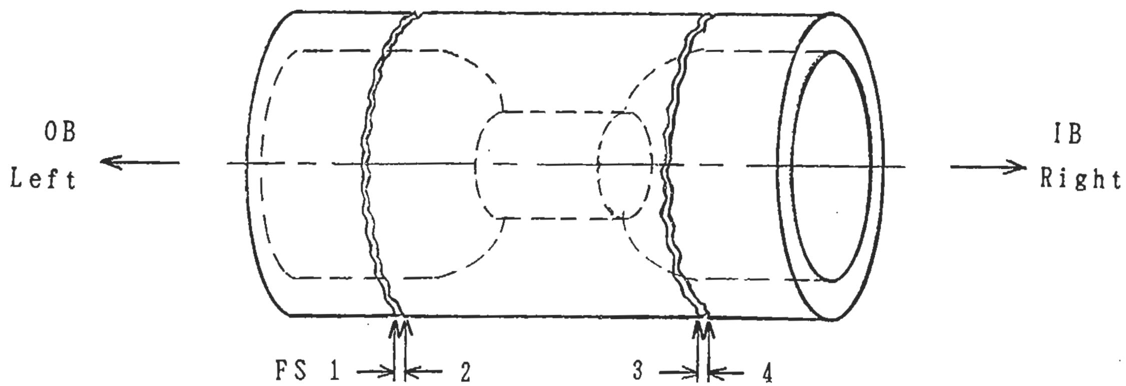


Fig.4 Photo of Pylon Rear Mount Bulkhead Fitting from IB or Right Side



(a) Macro- photo



(b) Schematic

Fig.5 Macro- photo and Schematic of Upper Link FWD Fuse Pin

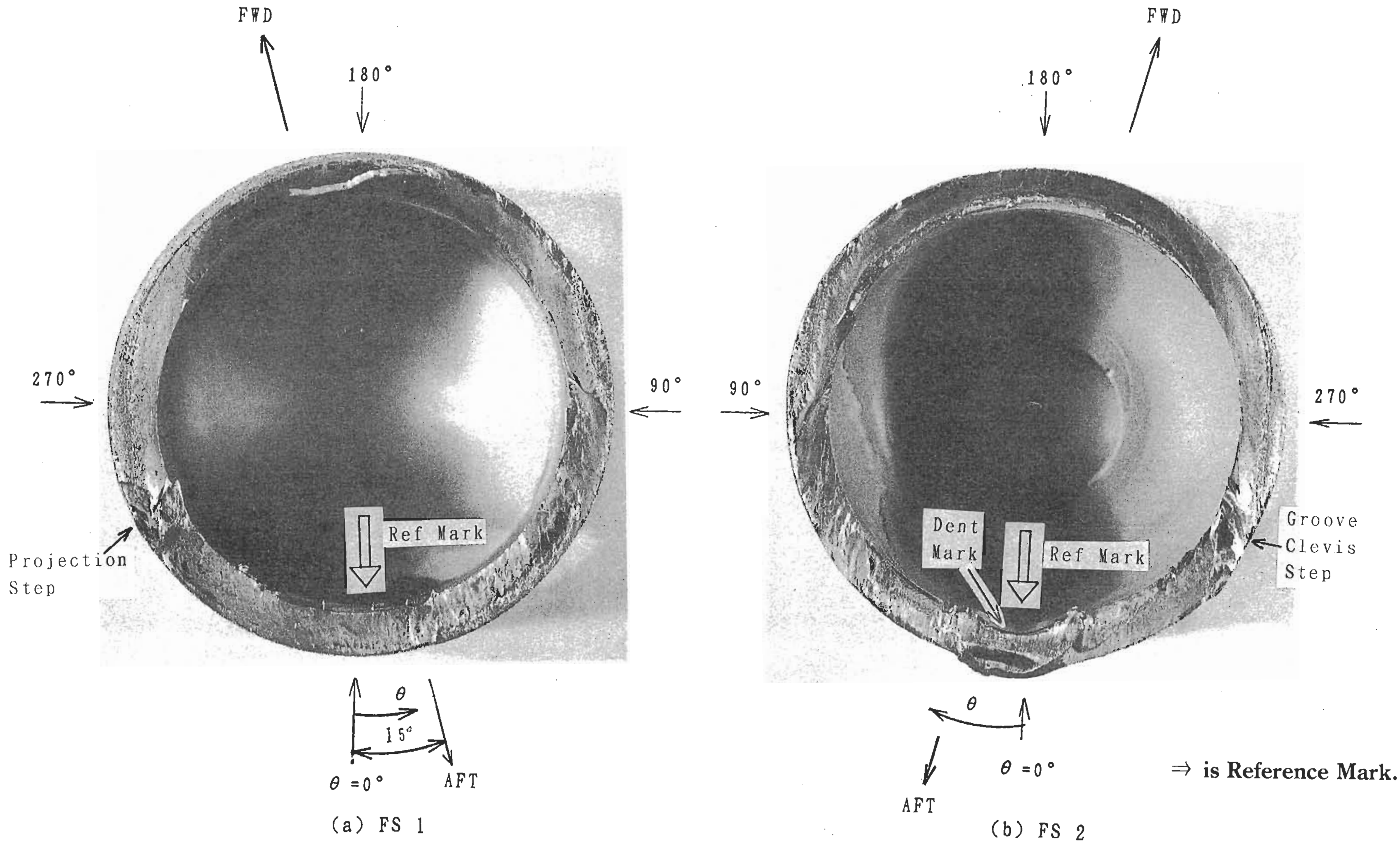


Fig.6-1 Macro-photos (part 1, FS 1 and 2) of Fractured Surfaces of Upper Link FWD Fuse Pin

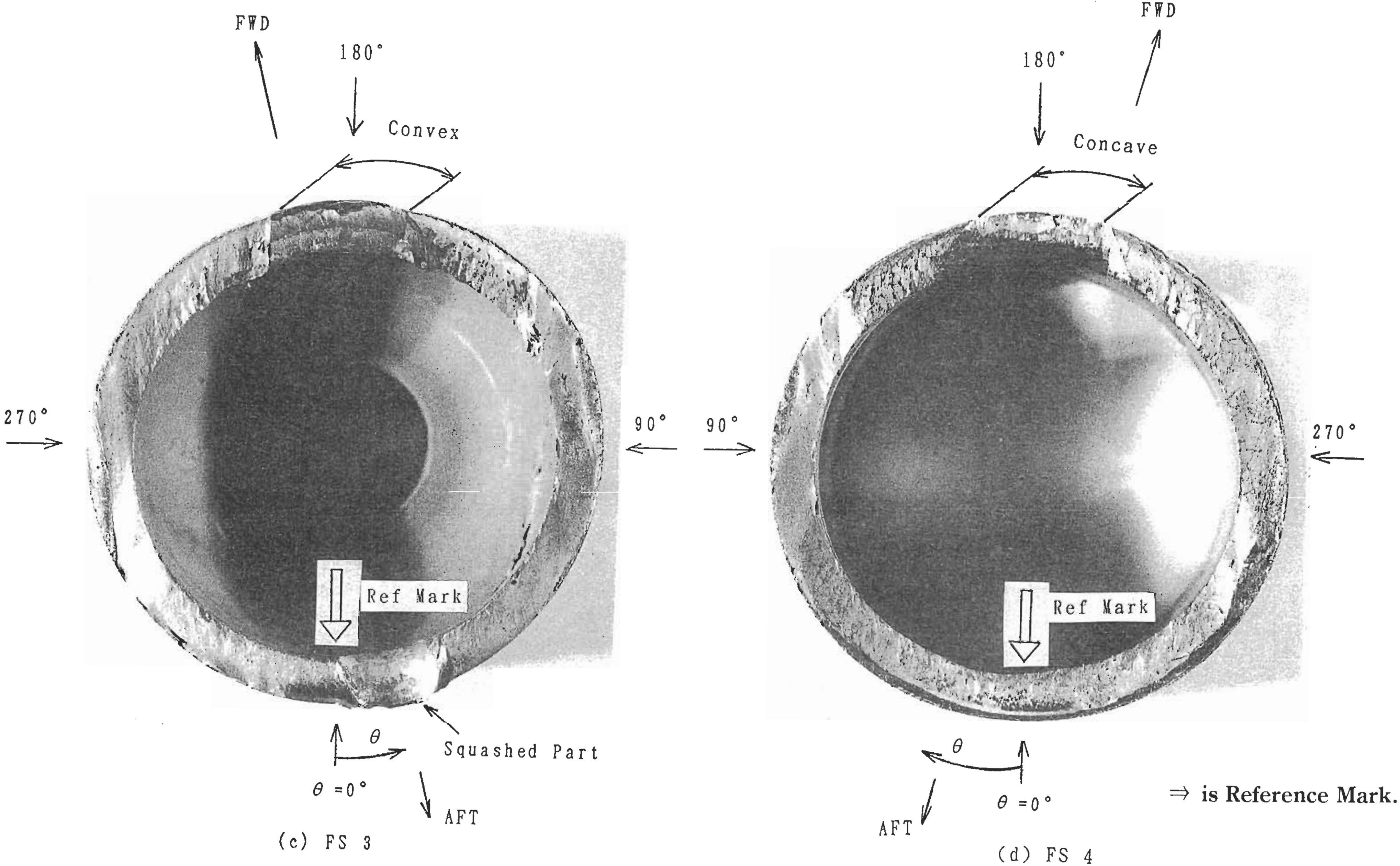


Fig.6-2 Macro-photos (part 2, FS 3 and 4) of Fractured Surfaces of Upper Link FWD Fuse Pin

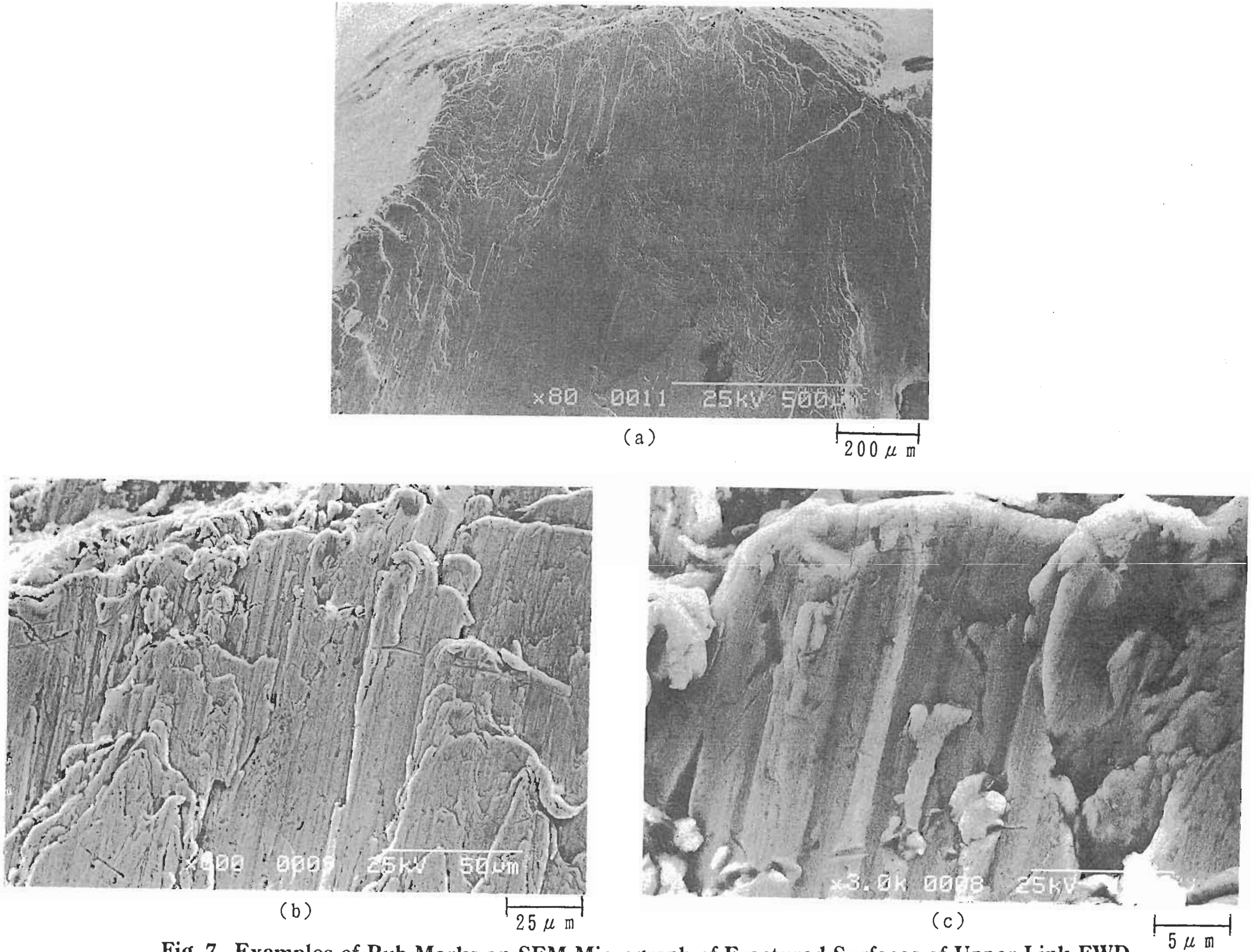
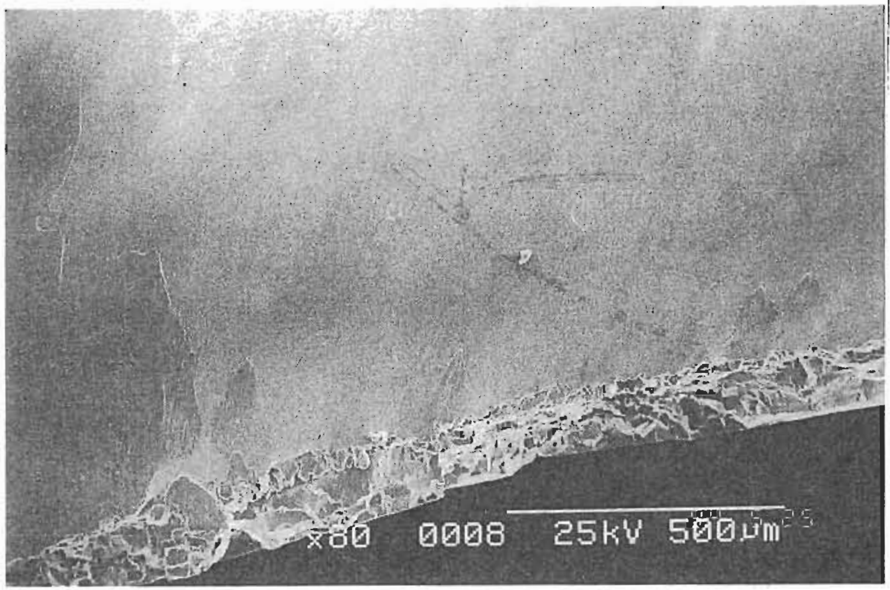
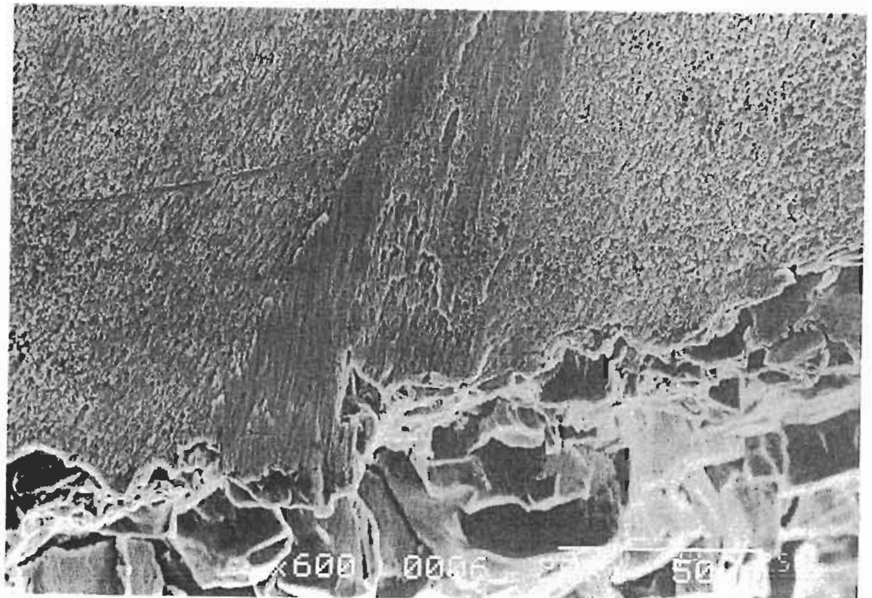


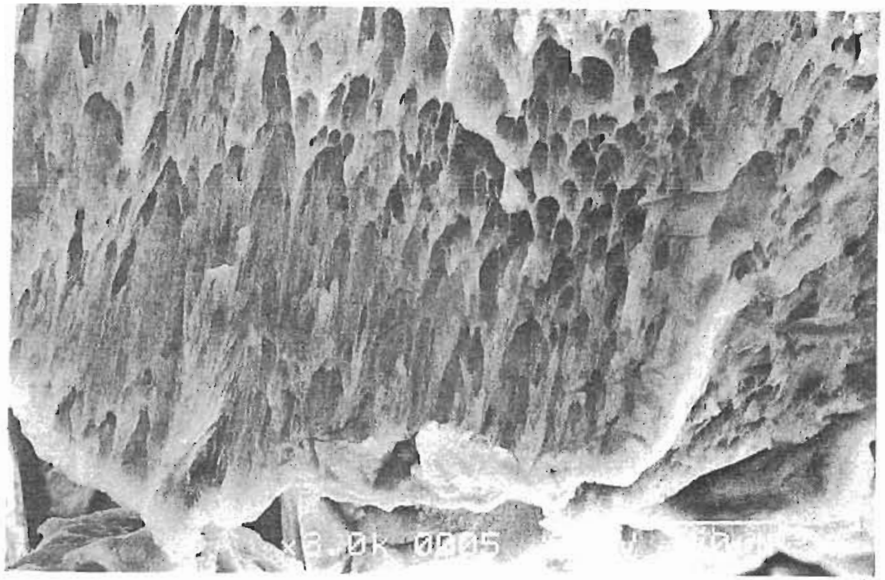
Fig. 7 Examples of Rub Marks on SEM Micrograph of Fractured Surfaces of Upper Link FWD Fuse Pin (FS 2, $\theta = 0^\circ$, Inside)



(a) 200 μ m



(b) 25 μ m



(c) 5 μ m

Fig.8-1 Examples of Dimples on SEM Micrograph of Fractured Surfaces of Upper Link FWD Fuse Pin (Part 1, FS 2, $\theta = 0°$, Outside)

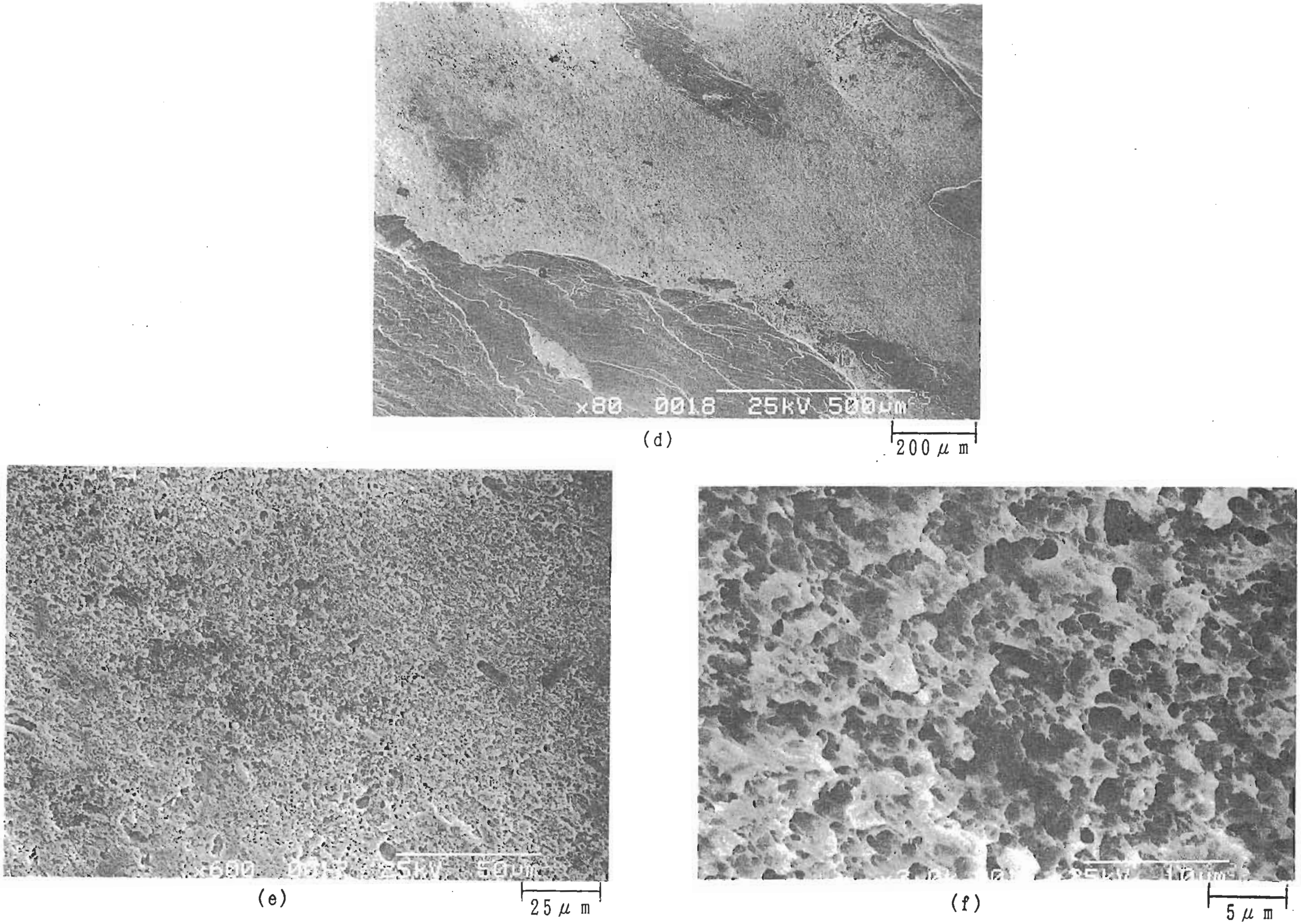
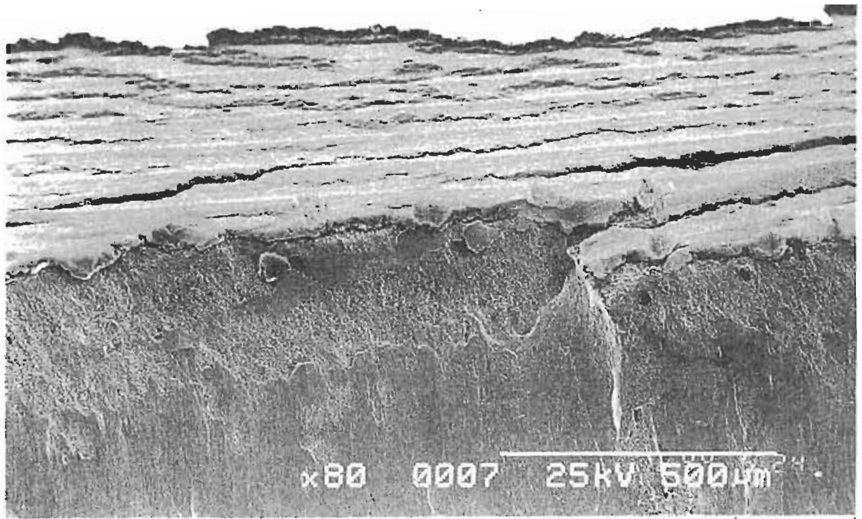
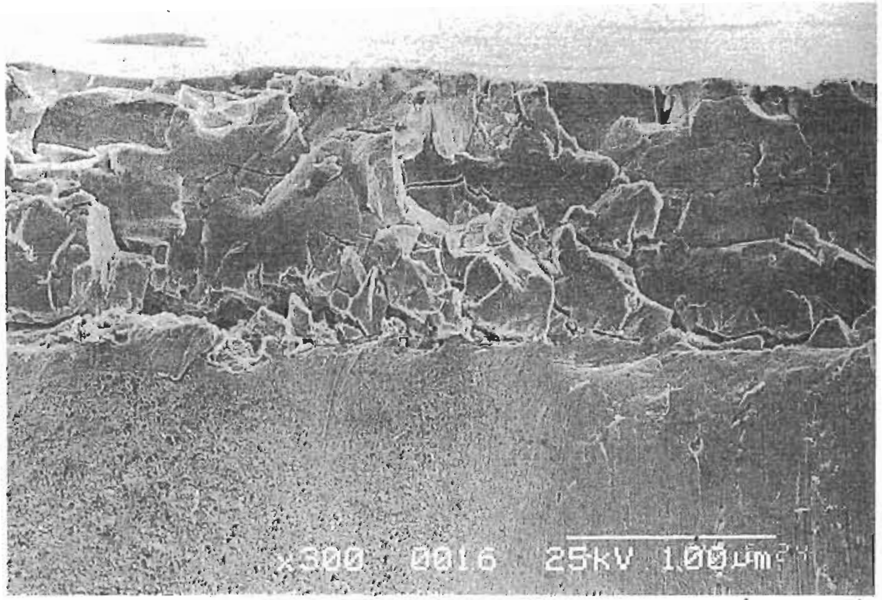


Fig.8-2 Examples of Dimples on SEM Micrograph of Fractured Surfaces of Upper Link FWD Fuse Pin (Part 2, FS 2, $\theta = 90°$, Center)



(a) Painted Inner Surface (FS 3、 θ =0°)

200 μ m



(b) Chromium Plated Outer Surface (FS 2、 θ =180°)

50 μ m

Fig.9 Micro-photos of Cadmium Paint and Chromium Layer of Upper Link FWD Fuse Pin

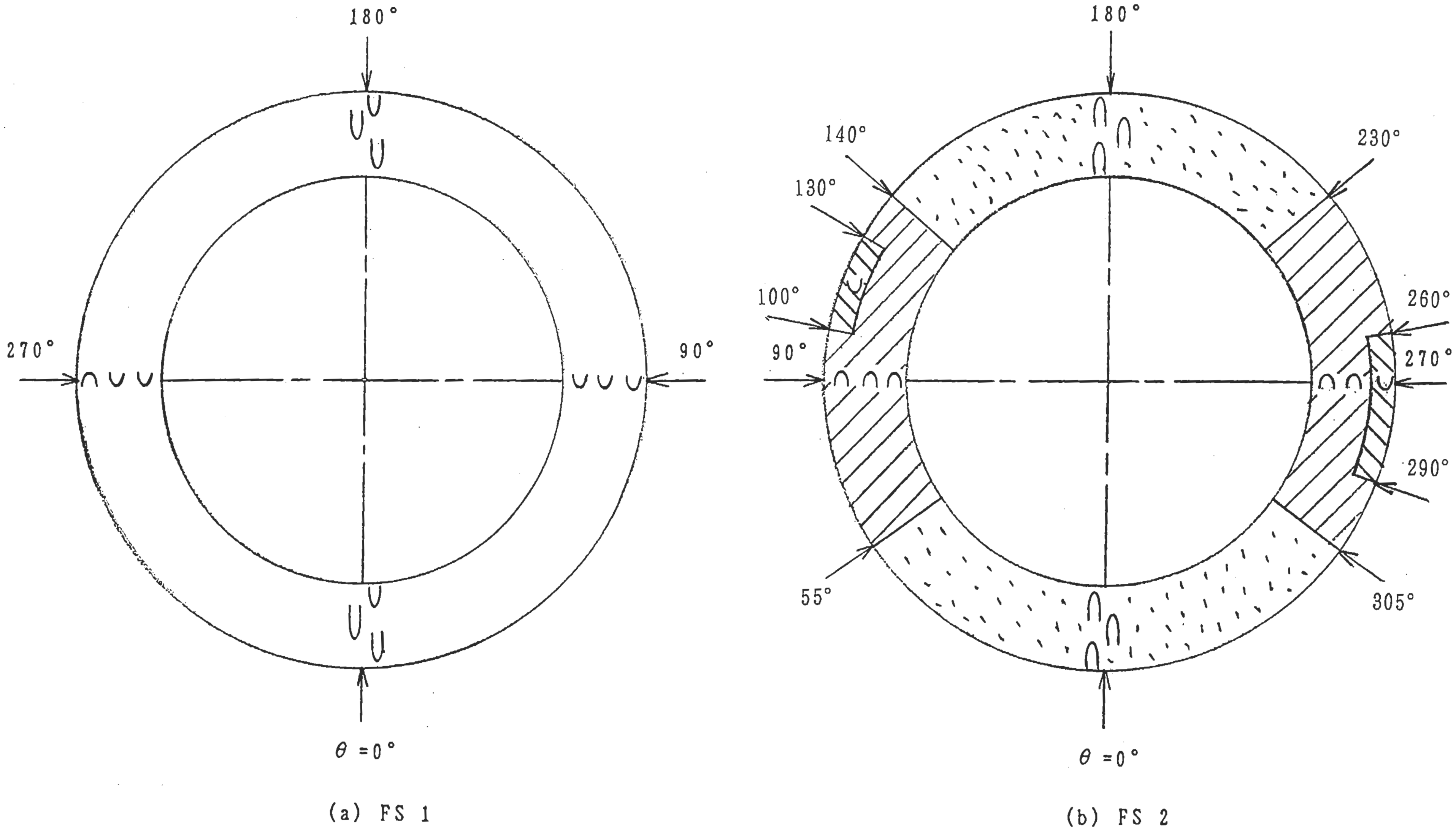


Fig.10-1 Directions of Dimples on Fractured Surfaces of Upper Link Fwd Fuse Pin (Part 1, FS 1 and 2)

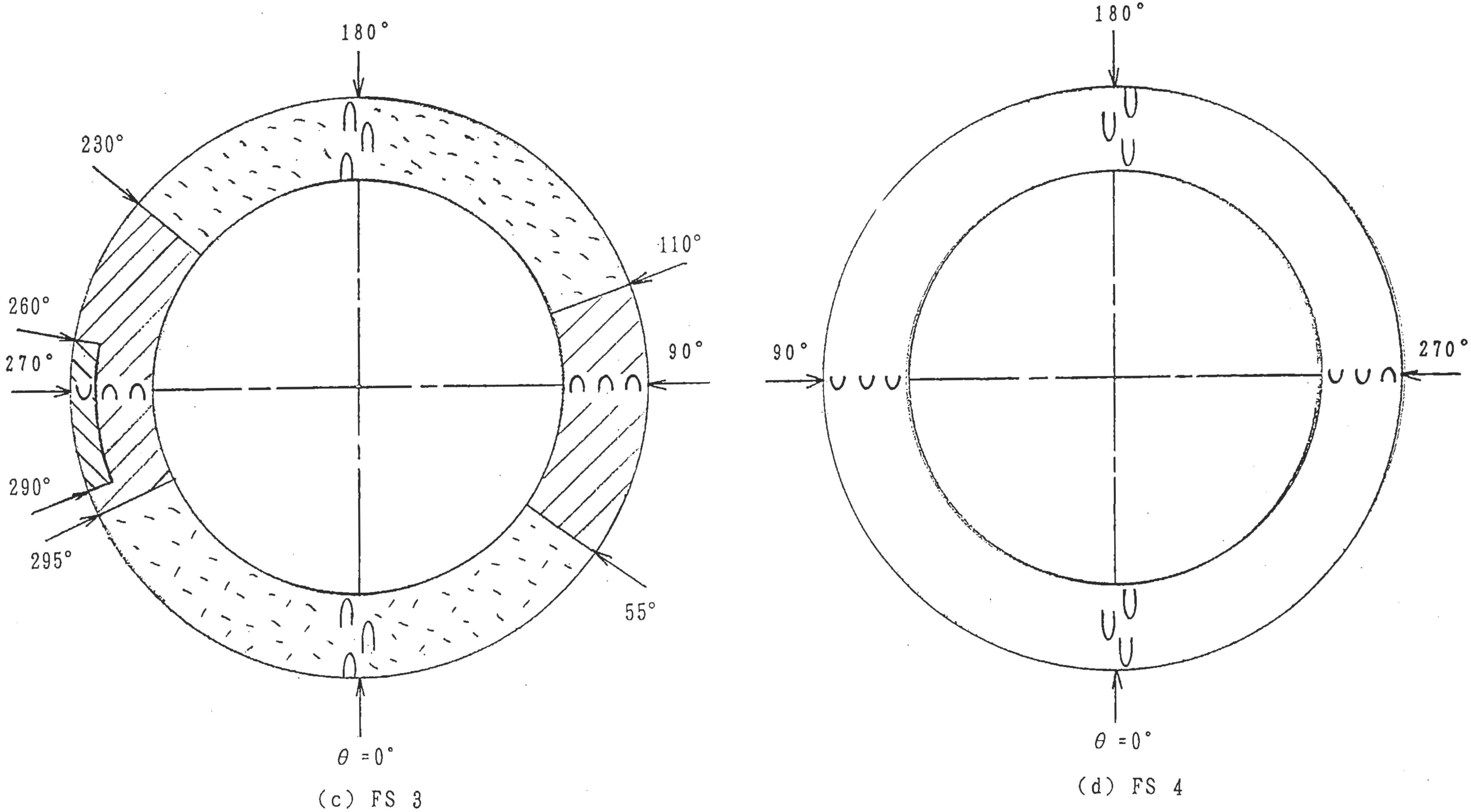


Fig.10-2 Directions of Dimples on Fractured Surfaces of Upper Link Fwd Fuse Pin (Part 2, FS 3 and 4)

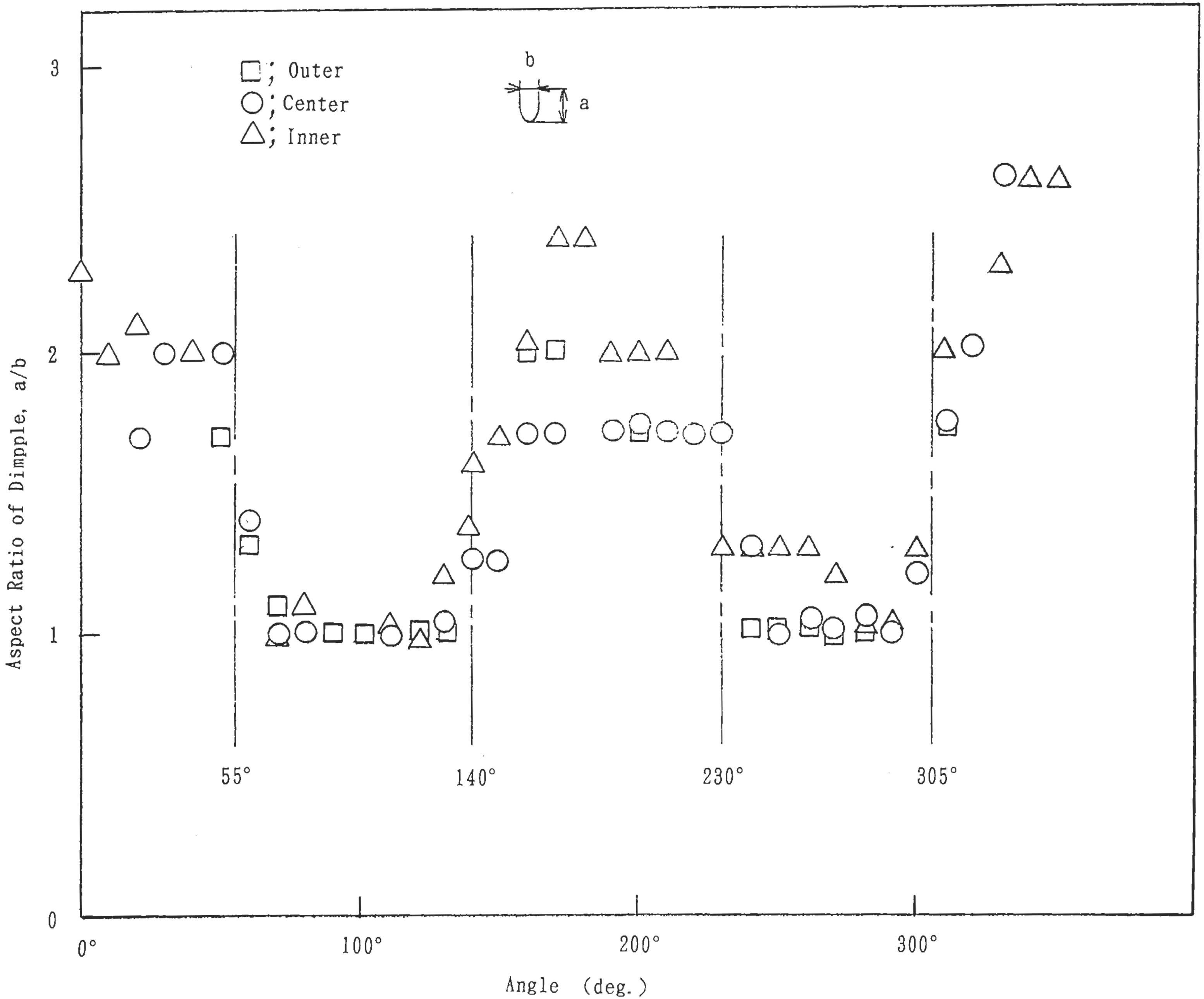


Fig.11-1 Aspect Ratio of Dimples on Fractured Surfaces of Upper Link FWD Fuse Pin (Part 1, Fractured Surface 2)

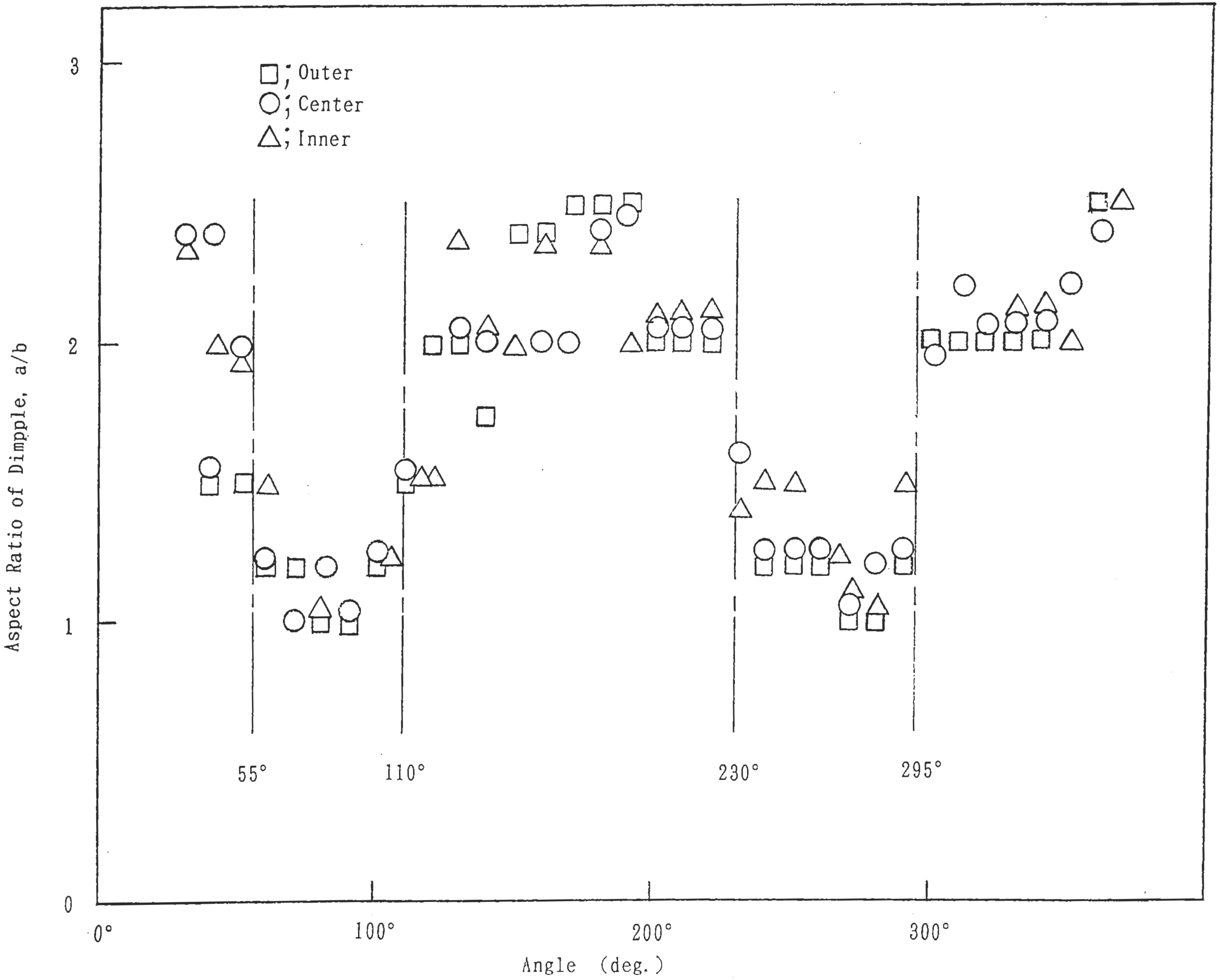


Fig.11-2 Aspect Ratio of Dimples on Fractured Surfaces of Upper Link FWD Fuse Pin (Part 2, Fractured Surface 3)

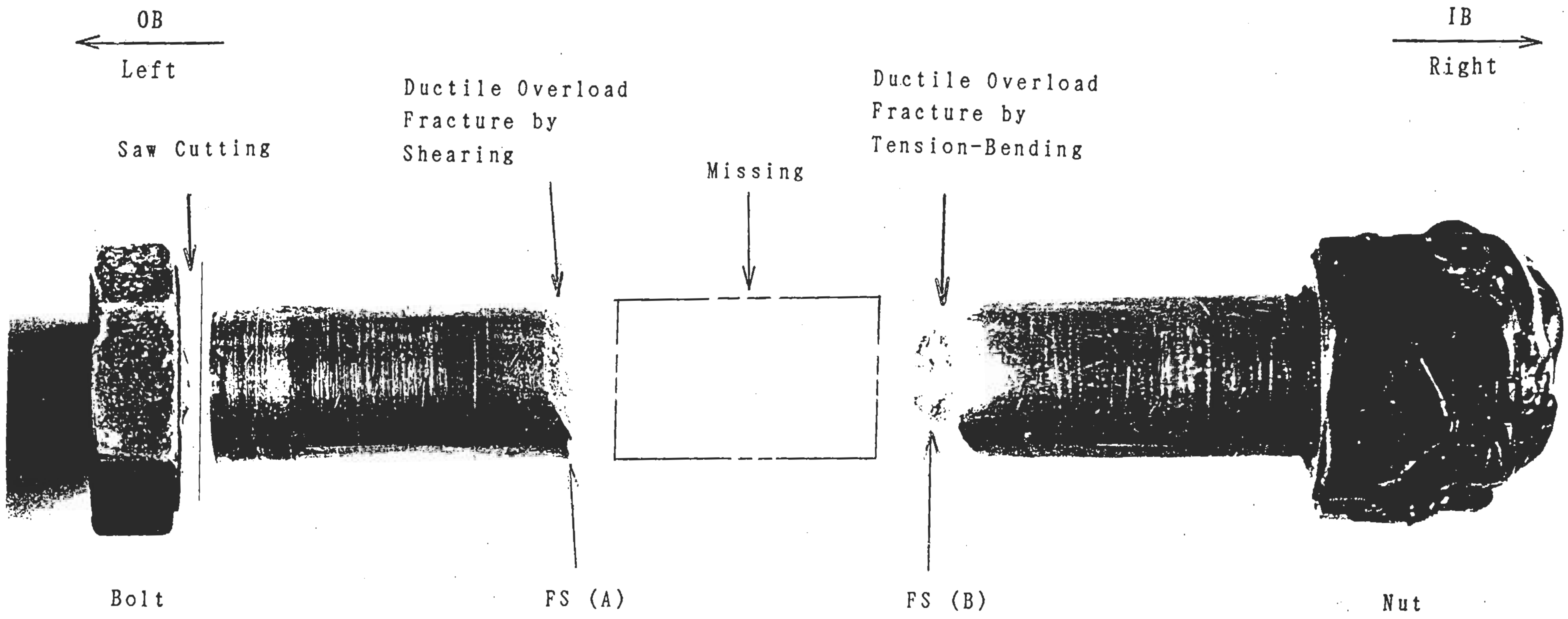
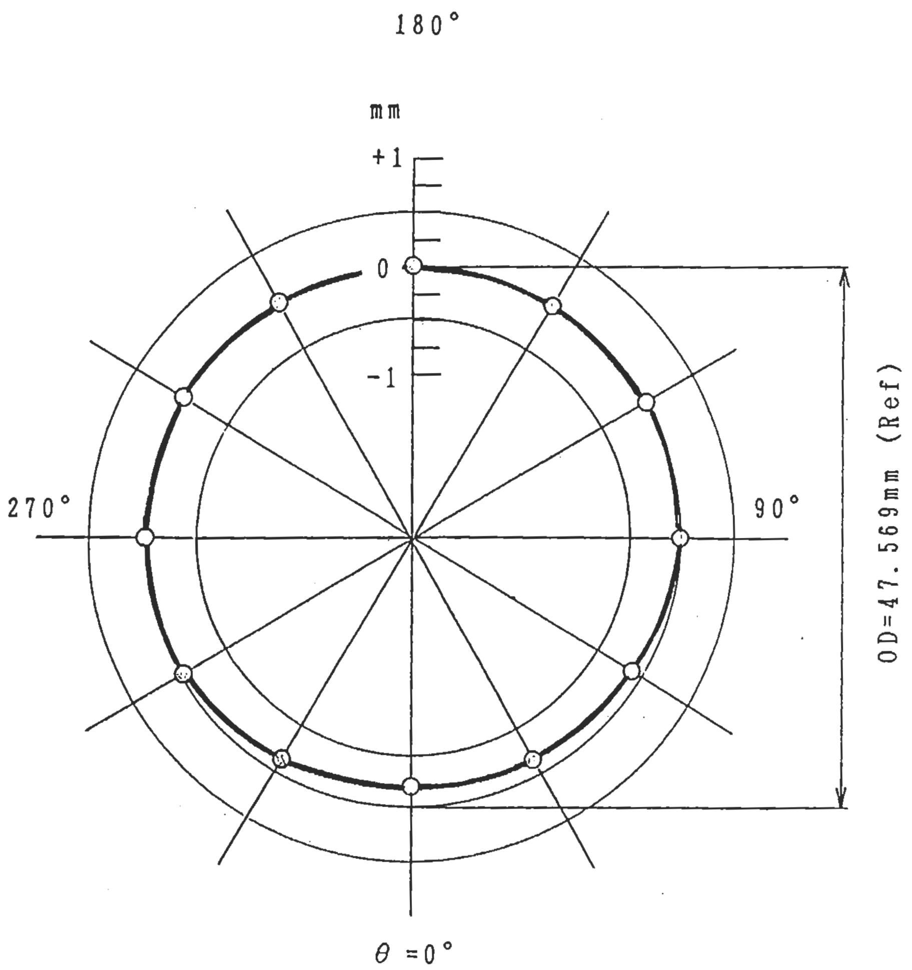
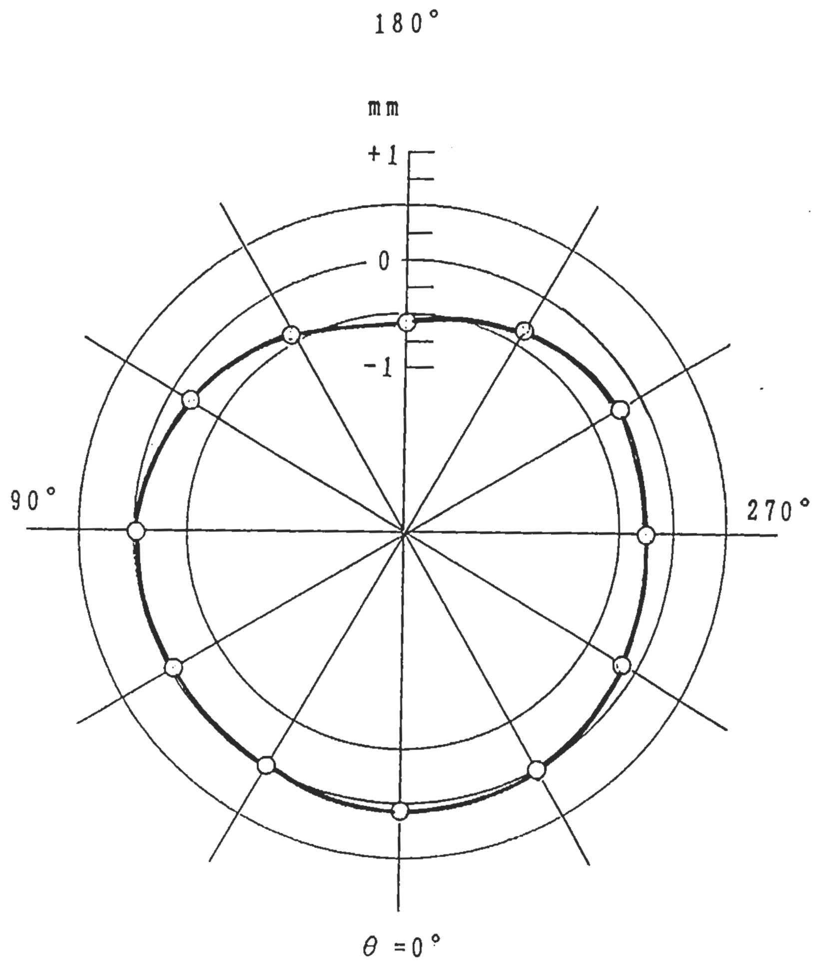


Fig.12 Macro- photo of Tightening Bolt for Upper Link FWD Fuse Pin

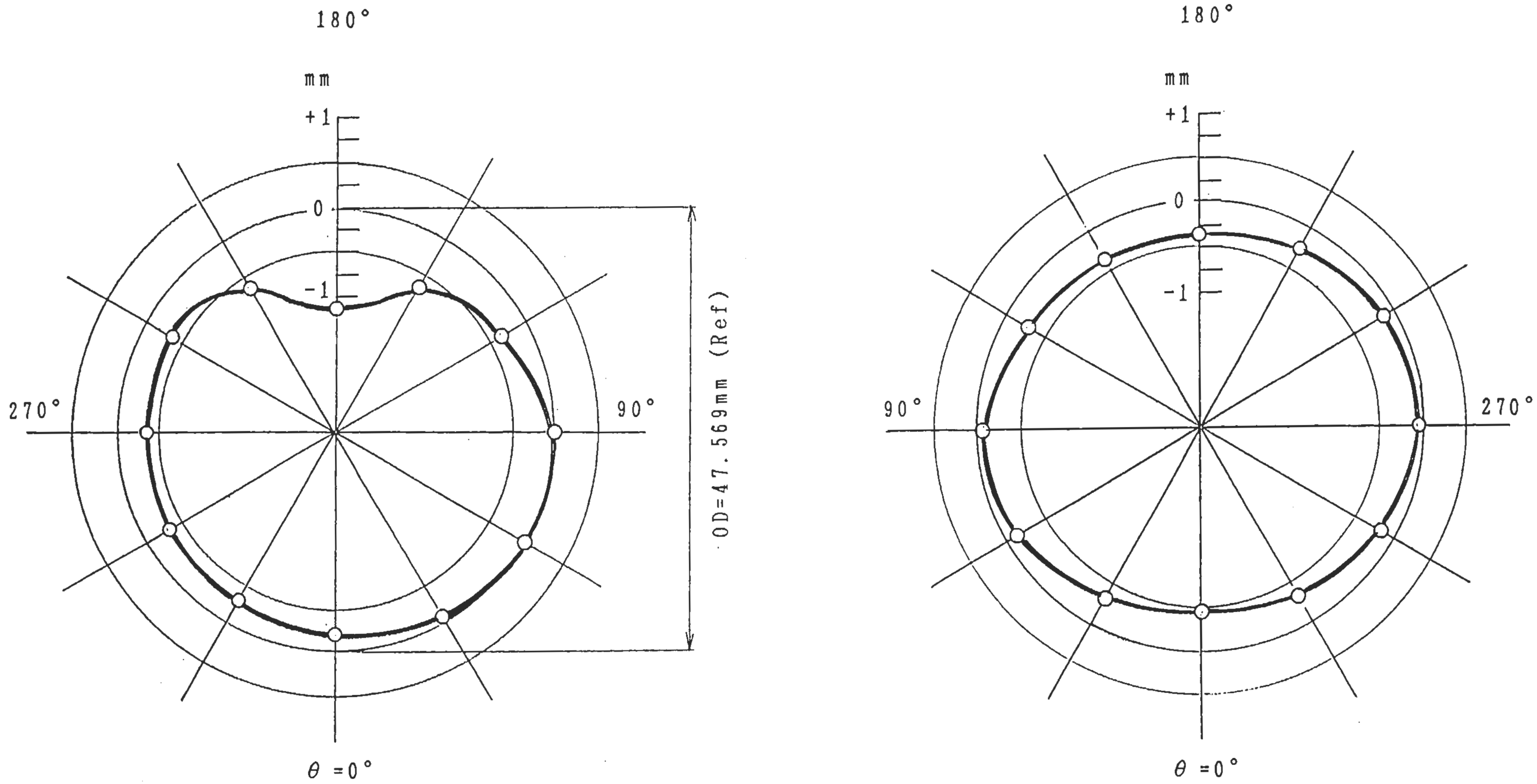


(a) FS 1



(b) FS 2

Fig.13−1 Deformation of Outside Diameter of Upper Link FWD Fuse Pin (Part 1, FS 1 and 2)



(c) FS 3

(d) FS 4

Fig.13−2 Deformation of Outside Diameter of Upper Link FWD Fuse Pin (Part 2, FS 3 and 4)

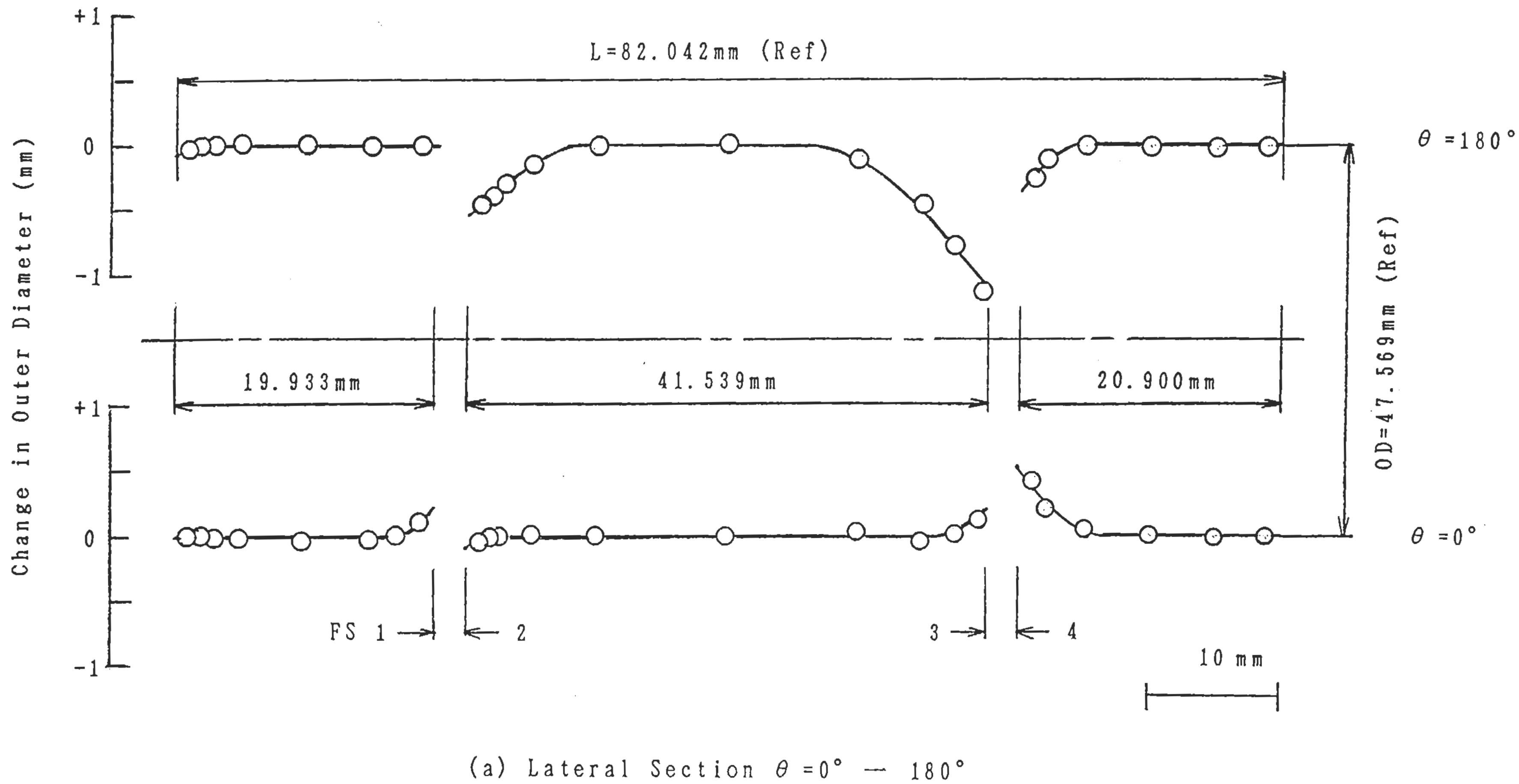
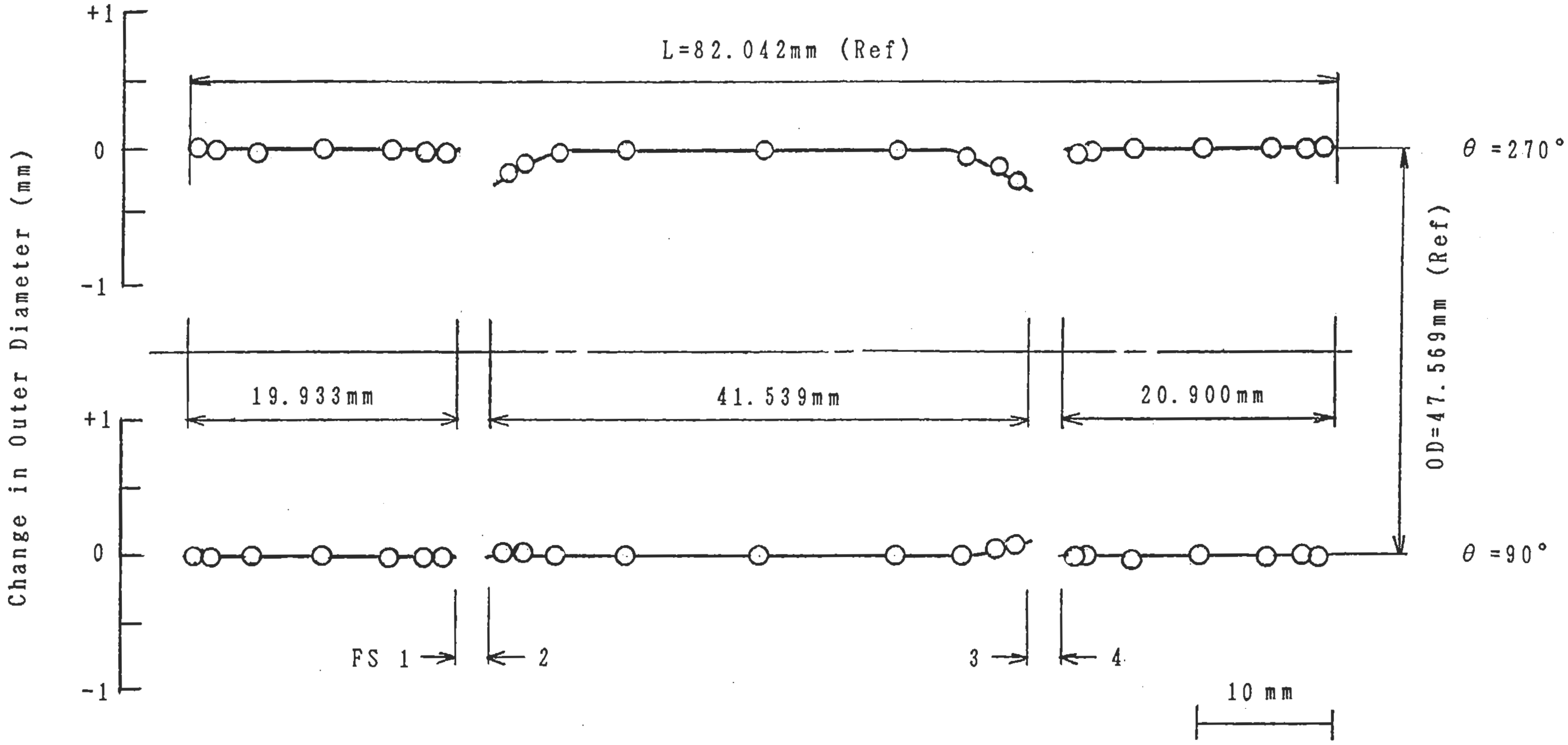
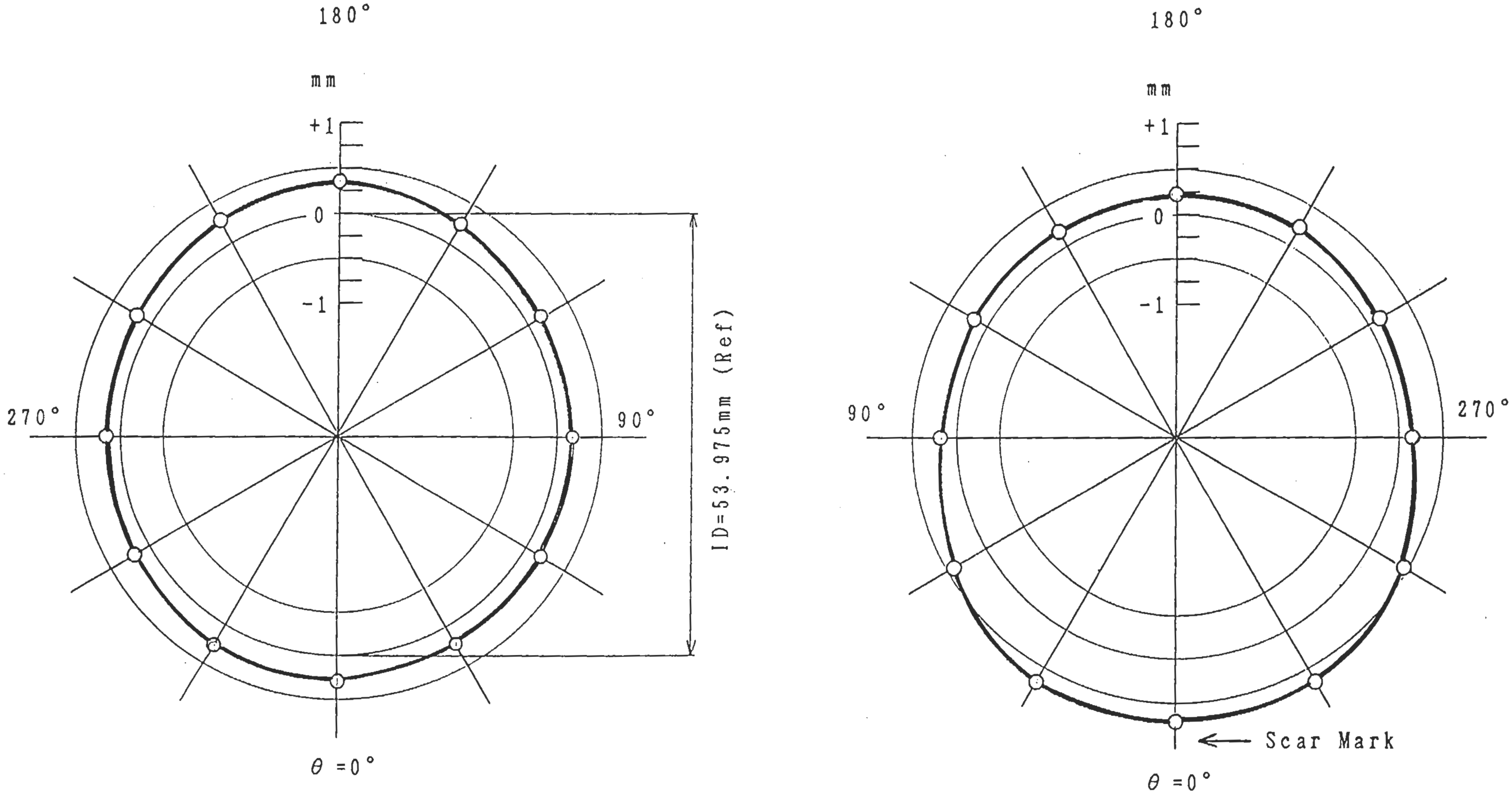


Fig.14 Change of Outside Diameter of Upper Link FWD Fuse Pin in Axial Direction (Part 1, Positions at θ = 0 ° and 180 ° from Reference Mark)



(b) Lateral Section θ =90° — 270°

Fig.14 Change of Outside Diameter of Upper Link FWD Fuse Pin in Axial Direction (Part 2, Positions at θ = 90° and 270° from Reference Mark)



(a) OB or Left Side

(b) IB or Right Side

Fig.15 Change of Inside Diameter of Pylon Rear Mount Bulkhead Fitting (Measured using molded silicone rubber at the Site (Narita A/P))

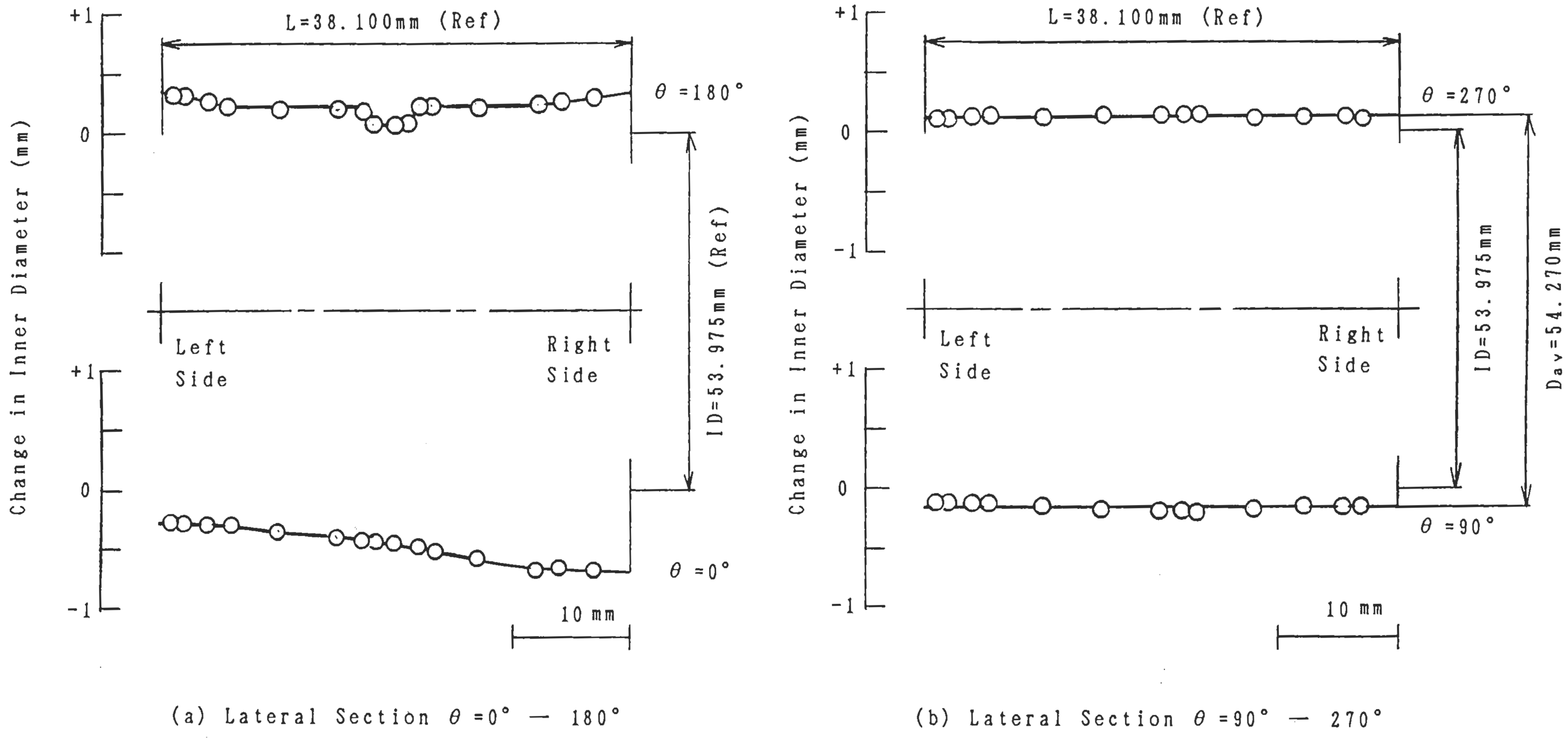
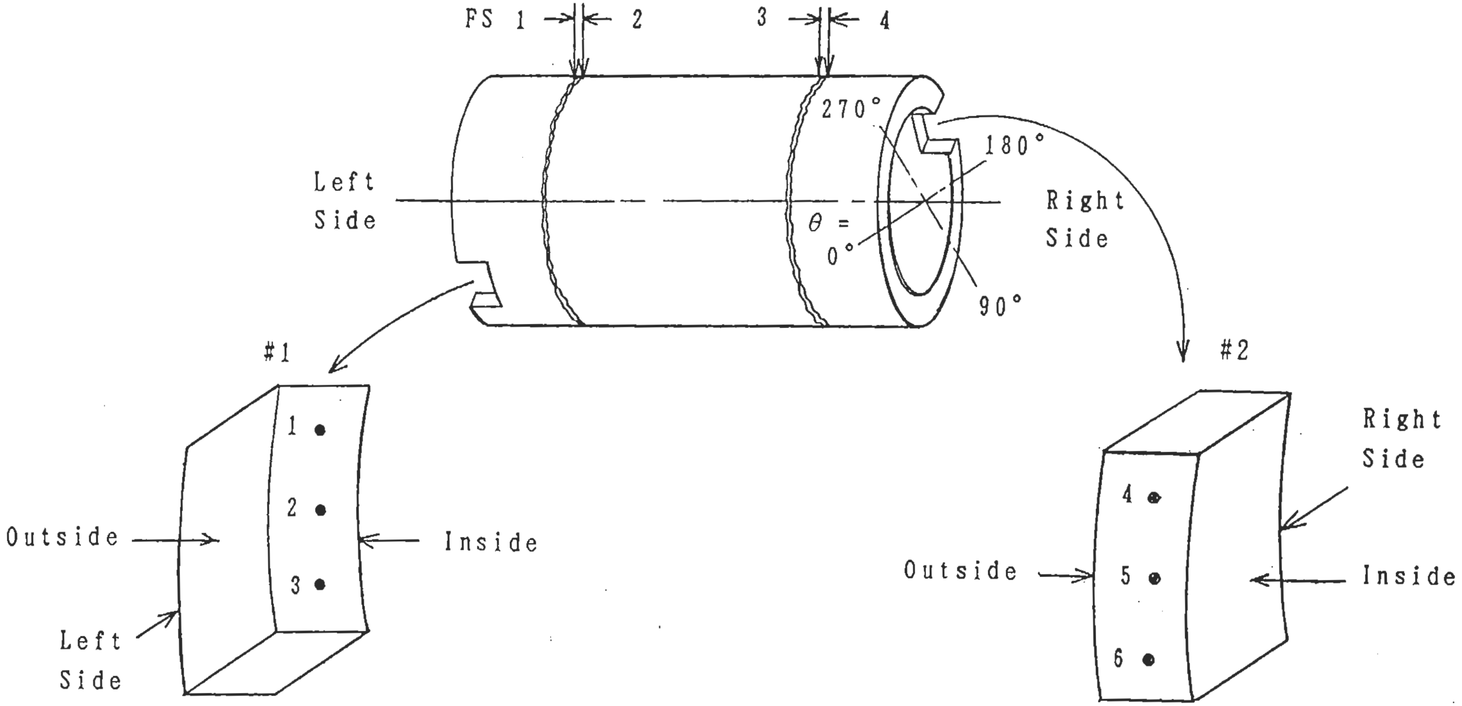
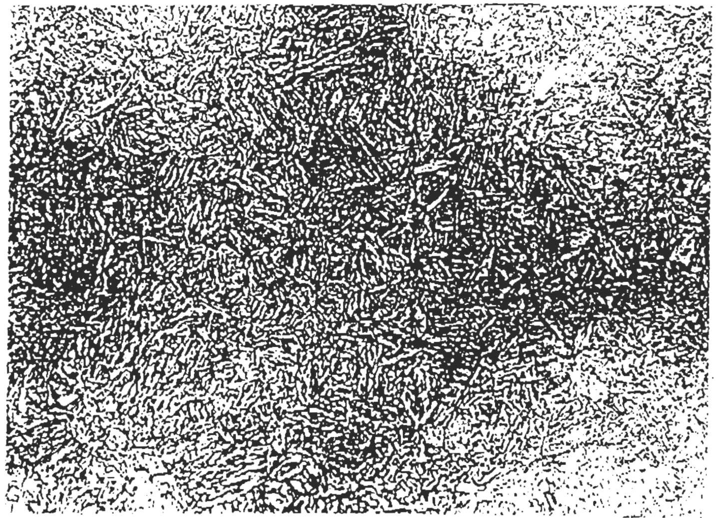


Fig.16 Change of Inside Diameter of Pylon Rear Mount Bulkhead Fitting in Axial Direction



(a) Vickers Hardness(HV20)

#2



(b) Microstructure

25 μm

Fig.17 Hardness Measurement and Photo of Micro–structure of Upper Link FWD Fuse Pin

1. Fuse Pin

(1) The deformation of the outside diameter of the fuse pin is small on No.1 and 4 fracture surfaces, and big on No.2 and 3 fracture surfaces. It is estimated that this difference was due to the fact that although the outside and the inside of No.1 and 4 fractured surfaces were restrained by the upper link and the insert, respectively, the inside of No.2 and 3 fractured surfaces was exposed to a cavity.

(2) It is estimated that the destruction of the fuse pin took place in the following sequence:

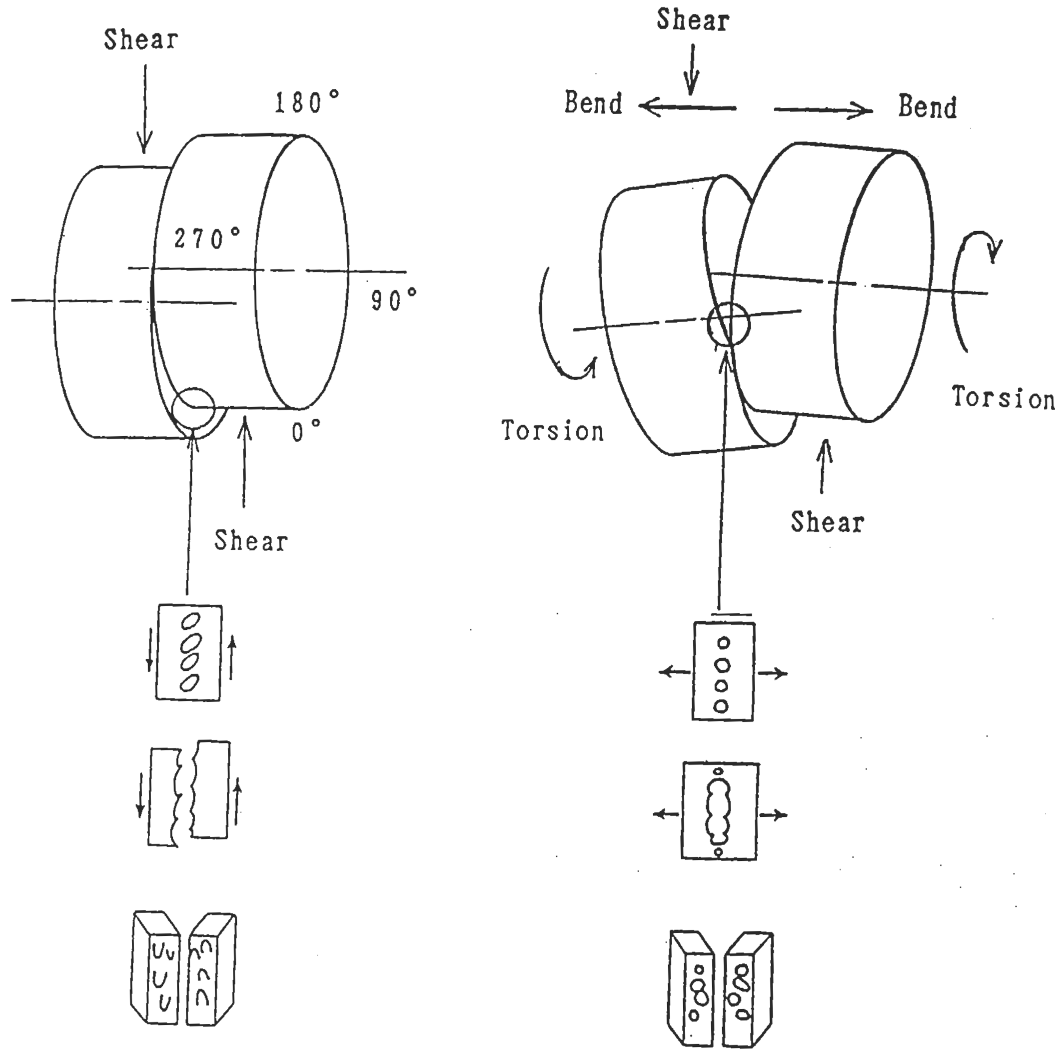
a The shearing destruction accompanied by elongated dimples starts from the vicinities of $\theta = 0°$, 180° .

b As a bending load is generated in the vicinities of remaining 90° and 270° portions, the co-axial dimples begin to appear, and the rupture takes place first in the vicinity of 90° portion.

c Finally, the rupture is completed in the vicinity of 270° portion, but at this point of time, a torsion load is also applied, reversing the dimples on the outside and the inside.

2. Pylon Rear Mount Bulkhead Fitting

1 The inner diameter of the hole of the fitting in the direction of 0° ~180° was 0.4 ~ 0.8 mm greater than that in the direction of 90° ~ 270° .



(a) Early phase ··· Elongated dimples (b) Later phase ··· Co-axial dimples

Figure 18 Summary of Destruction and Deformation

1 Force deforming Pylon Rear Mount Bulkhead Fitting

From the fact that the pylon rear mount bulkhead fitting was deformed into an oval shape with the 0° ~ 180° direction, i.e. the direction of exterior force as the major axis as shown in Figure 14, it was presumed that the hatched portion in Figure a shown below had yielded. Based on this, the force which deformed the fitting can be obtained from the equation (1) shown below.

$$F \geqq A_1 \times \sigma_r$$
$$= 1003 \text{ kN} \quad \cdots\cdots\cdots \quad (1)$$

where

$A_1 = W \times (D - d)$

(Area of the fitting. Based on design dimensions shown in Figure a .)

Figure (a) Design Dimensions of Pylon Rear Mount Bulkhead Fitting

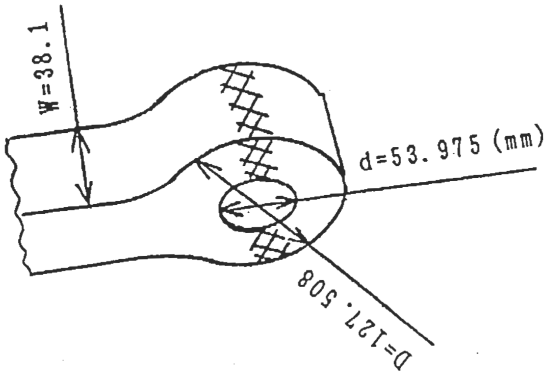


Figure (a) Design Dimensions of Pylon Rear Mount Bulkhead Fitting

2 Shearing Force applied to Fuse Pin

Assuming that the force obtained from the equation (1), the shearing force τ generated in the fuse pin can be obtained from the equation (2).

$$\tau = (F/2)/A_2$$
$$= 857 \text{ MPa} \quad \cdots\cdots\cdots \quad (2)$$

where

$A_2 = 5.85 \times 10^{-4}$ m²

(Cross section of the fuse pin.)

On the other hand, according to the results of the fatigue data sheet project of the Metallic Materials Technology Laboratory, the tensile strength σ_B is :

$$\sigma_B = 1365 \pm 34 \text{ Mpa} \quad \cdots\cdots\cdots \quad (3)$$

$\sigma_B = 1365$ MPa is obtained as an average.

If this value is converted using the Mises equation ($\tau = \sigma / \sqrt{3}$), the shearing stress corresponding to the tensile strength σ_B becomes 788 Mpa.

And according to Boeing, the tensile strength of the fuse pin is close to the valure, $\sigma_B = 1365$ Mpa.

Figure 19 Load deforming Pylon Rear Mount Bulkhead Fitting and Shearing stress applied to Fuse Pin

Appendix 2 NTSB's Special Investigation Report (Excerpt)

NTSB/SIR-94/02

PB94-917006

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

SPECIAL INVESTIGATION REPORT

MAINTENANCE ANOMALY RESULTING IN DRAGGED ENGINE DURING LANDING ROLLOUT

NORTHWEST AIRLINES FLIGHT 18
BOEING 747-251B, N637US
NEW TOKYO INTERNATIONAL AIRPORT
NARITA, JAPAN
MARCH 1, 1994

Adopted: December 20, 1994
Notation 6487

Abstract: This special investigation report addresses the maintenance activity at Northwest Airlines that led to the accident involving Northwest Airlines flight 18, a B-747, during the airplane's intermediate stop at Narita, Japan, while it was flying from Hong Kong to John F. Kennedy International Airport, Jamaica, New York, on March 1, 1994. Safety issues in the report focused on maintenance operations and maintenance work environments. Safety recommendations concerning these issues were made to the Federal Aviation Administration and to Northwest Airlines.

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20594

SPECIAL INVESTIGATION REPORT

MAINTENANCE ANOMALY RESULTING IN DRAGGED ENGINE DURING LANDING ROLLOUT

NORTHWEST AIRLINES FLIGHT 18
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1. FACTUAL INFORMATION

1.1 Flight Synopsis

On March 1, 1994, Northwest Airlines (NWA) operated flight 18, a B-747-251B, from Hong Kong to John F. Kennedy International Airport, Jamaica, New York, with an intermediate stop at New Tokyo International Airport, Narita, Japan. According to the captain and first officer, the flight, touchdown, and initial landing rollout at Narita, around 1340 Japanese Standard Time, were routine. Engine thrust reversing was normal on all four engines until the flightcrew moved the engine power levers out of reverse thrust at about 90 knots. During the rollout, the No. 1 engine and pylon rotated downward about the midspar pylon-to-wing fittings into a position in which the lower forward part of the engine nose cowl contacted the runway. The primary forward upper link fuse pin was later found fractured within the No. 1 engine pylon.

The airplane was subsequently stopped on a taxiway, with the front of the No. 1 engine still contacting the ground. The lower forward engine nose cowl had been ground away as it slid along the runway. (See figure 1). A fire near the No. 1 engine was rapidly extinguished by local fire fighters, and all passengers remained aboard. They were subsequently deplaned via portable boarding stairs about 30 minutes after the airplane was brought to a stop. There were no injuries.

Figure 1.--No. 1 engine.

1.2 Special Investigation Protocol

The accident that precipitated this special investigation occurred at New Tokyo International Airport, Narita, Japan. The accident and the events leading up to it are being investigated by the Japanese Aircraft Accident Investigation Commission (JAAIC), in accordance with procedures outlined in Annex 13 to the Chicago Convention on International Civil Aviation. The Safety Board assisted the JAAIC, also in accordance with Annex 13, by gathering data at the Northwest Airlines, Inc., (NWA) maintenance base in St. Paul, Minnesota, on maintenance activity regarding the accident airplane. The Safety Board also examined a copy of the cockpit voice and digital flight data recorder tapes. The data gathered by the Safety Board were provided to the JAAIC in June 1994.

The Safety Board performed this special investigation because of the ramifications to the US aviation industry of the maintenance anomaly that precipitated the accident. The Safety Board acknowledges that this report and the Japanese accident investigation report will contain many common elements. However, it should be emphasized that the full report of the investigation will be issued by the government of Japan. This special investigation report addresses the activity at the NWA maintenance facility that led up to the accident and will only briefly describe the operational aspects of the flight and landing at Narita.

As part of the investigation, the Safety Board conducted 18 interviews of NWA maintenance employees, including mechanics, inspectors, and management personnel. The Safety Board also interviewed two Federal Aviation Administration (FAA) maintenance inspectors assigned to oversee the NWA maintenance operations. Appendix B contains summaries of the interviews. The Safety Board also gathered information related to similar maintenance anomalies at airlines other than NWA. Routine Safety Board investigation procedures were followed during this special investigation. Parties involved were the FAA, NWA, the Air Line Pilots Association (ALPA), the Boeing Commercial Airplane Group, and the International Association of Aerospace Workers and Machinists (IAM).

1.3 Failure of the Engine Support Fittings

The fractured forward upper link fuse pin from the No. 1 pylon was recovered in three pieces and was retained by the JAAIC for metallurgical examination. Examination of the pin revealed that it fractured in static overload and that there was no evidence of preexisting fatigue.

Prior to this landing, at some unknown time, the aft fuse pin on the pylon diagonal brace had migrated out of its fitting. The pin was found loose in the pylon structure. It was intact, undamaged, and had no evidence of preexisting defects. The aft diagonal brace fuse pin is normally retained by both a primary retainer (two washer-like retainer caps and a through bolt) and a secondary retention clip (a bolt-on C-shaped bracket). (See figure 2). However, a search of the airplane pylon and engine area, as well as the runway surface at Narita, revealed neither the aft diagonal brace fuse pin primary nor secondary retaining devices.

The March 1, 1994, NWA Fleet Information Register indicates that the airline operates 41 B-747 airplanes of various models. NWA officials stated that 7 airplanes, numbers 6631, 6632, 6636, 6637 (the accident airplane), 6638, 6739 and 6740, of its 31 B-747 aircraft, have the secondary retainers installed on the aft diagonal braces, unless the third generation of pins had been installed. Third generation pins required no secondary retaining devices. (See figures 2 and 3).[1]

The airplane had accumulated 14 flight cycles since the most recent "C" check that was completed on February 21, 1994. A takeoff and subsequent landing constitute a flight cycle.

The day after the accident, NWA personnel advised the Safety Board and the JAAIC that a set of diagonal brace fuse pin primary and secondary retainers had been found in the NWA maintenance facility in an unmarked white cloth bag. According to NWA officials, the bag was found between the hand rail and a piece of "2 by 4" wooden board on the left under-wing work stand. This was adjacent to where work had been performed on the No. 1 engine of N637US. Prior to the accident, N637US had undergone a "C" check at that work stand in NWA's maintenance facility. The "C" check had included maintenance and inspection of the diagonal brace fuse pin lugs.

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[1]Because of the limited availability of the new third generation pins, the airline was installing the parts based on availability. As a result, any particular NWA B-747 airplane could have two different types of pins installed on the four engine pylons.

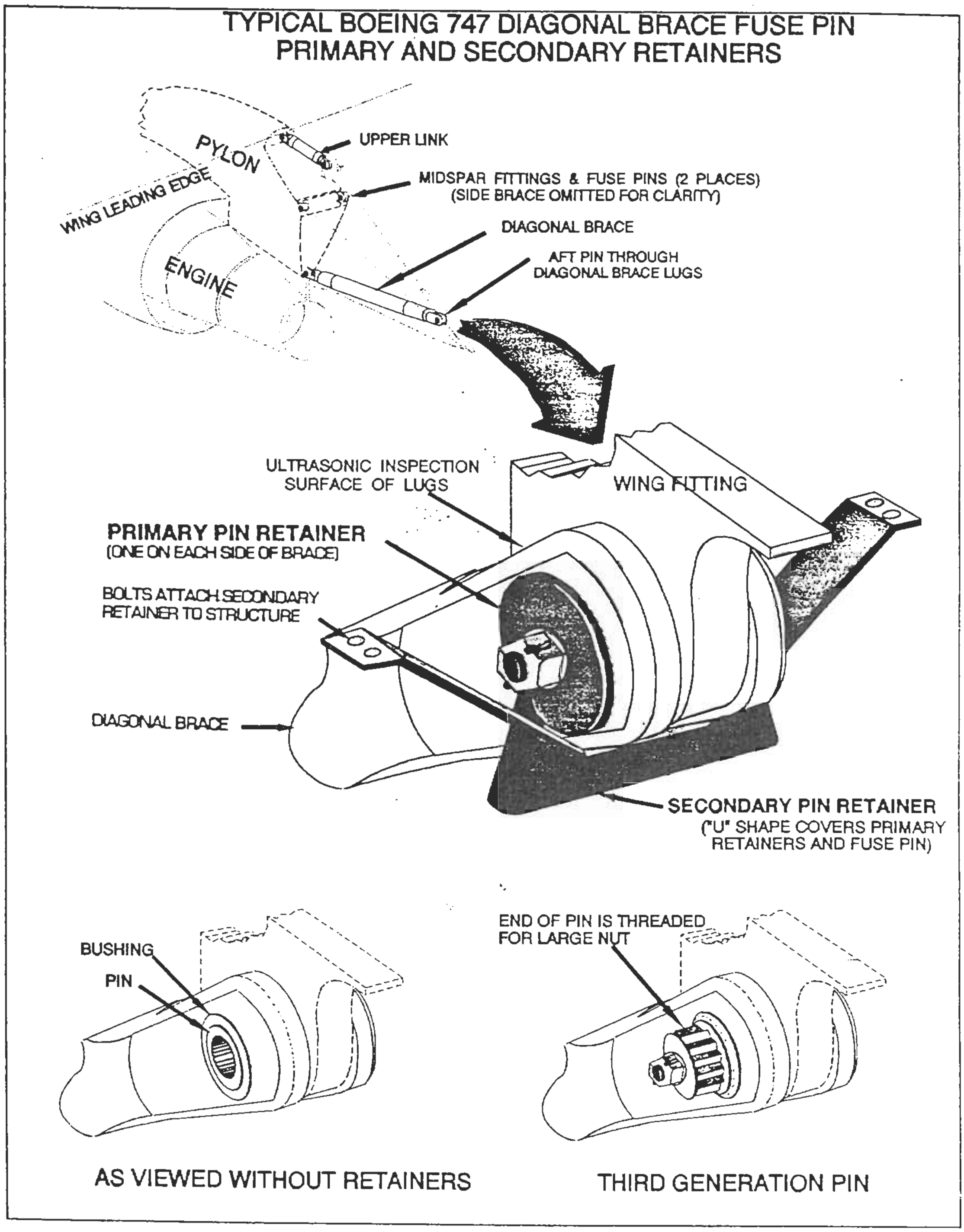

Figure 2.--Diagonal brace attachment details.

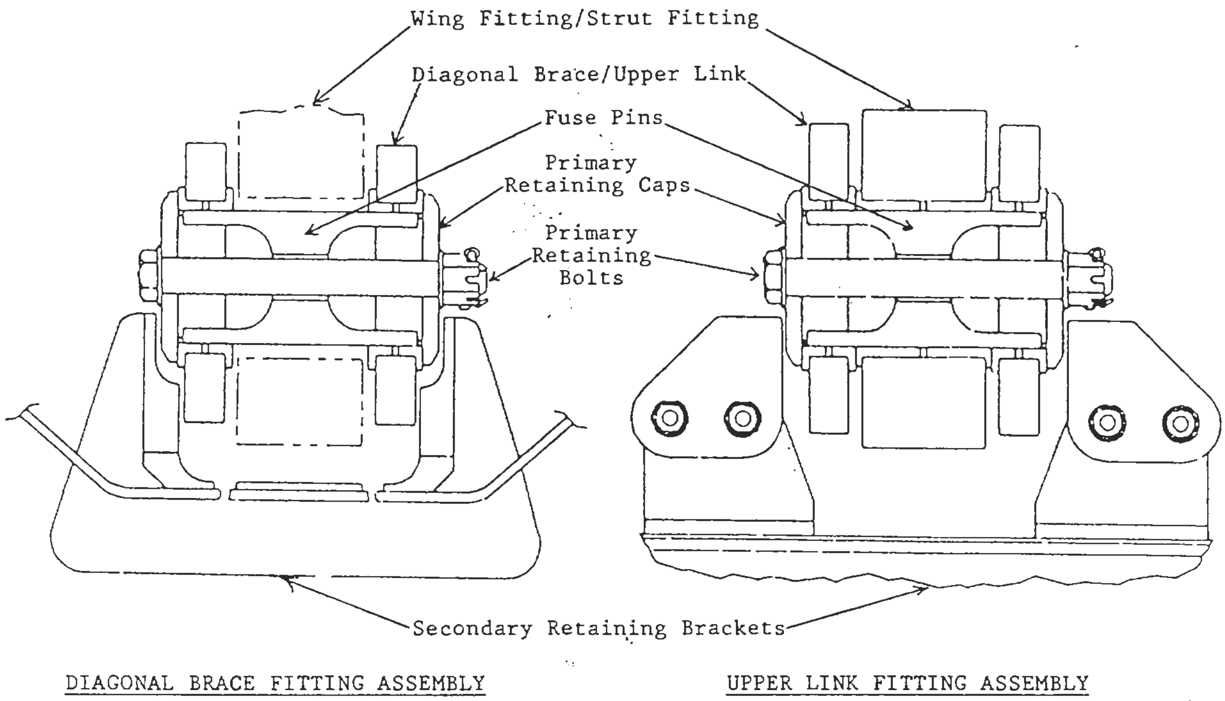

Figure 3.--Diagonal brace and upper link fitting assemblies.

1.4 General NWA Maintenance Procedures

NWA, with the approval of the FAA, had developed overall maintenance-related procedures in the years before the accident. As they relate to this accident, they included:

(1) Establishment of a General Engineering and Maintenance Manual (GEMM);

(2) The production of work planning instructions through a computerized system known as CITEXT;[2]

(3) Monitoring the completion of maintenance actions prescribed by CITEXT.

(4) Prominent display of red tags when vital components were disassembled or disconnected; and

(5) The requirement for a final inspection of maintenance actions taken, by individuals not involved in performing those maintenance actions, before approval can be given to close a work area.

1.4.1 General Engineering and Maintenance Manual (GEMM)

The GEMM contained the policies and general operating procedures for the NWA maintenance activities. These include work control procedures, policies for handling paperwork in the hangars, and the like.

1.4.2 CITEXT

According to NWA personnel, the CITEXT system had come to the airline from a merger with Republic Airlines in 1986 and replaced the hard copy, manually generated system then in use at NWA. The CITEXT-generated work cards followed the general instructions contained in the aircraft maintenance manuals. CITEXT policies and procedures are contained in the GEMM. CITEXT cards contain step-by-step instructions for the maintenance activity. NWA

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[2]A computer-generated maintenance instruction system. CITEXT (Centralized Interactive Text System) is a European-developed software system.

personnel estimated that about 95 percent of the routine maintenance procedures performed were generated by CITEXT, with the remainder coming from maintenance manuals or other instructions.

CITEXT work instructions were written as blocks of tasks. For example, a task might describe opening an access panel, performing a maintenance or inspection activity, and closing the panel. Maintenance planners would use a checklist to identify and organize the correct groups of work tasks. The planned activities were informally reviewed by another maintenance planner and signed by the planner's manager. The tasks were then printed as a sequence of work cards, each of which contained the step-by-step instructions for a maintenance or inspection activity, sign-off areas for maintenance and inspection personnel, and locations of reference information in the GEMM, maintenance manuals, or other sources.

The Lead Mechanics on the shop floor would assign work cards to the individual mechanics, who were to follow the steps called out to complete the tasks. Some groups of mechanics had been segregated into crews, such as a dedicated engine crew. When interviewed about receipt of work cards, several people stated that due to the repetition of using the CITEXT work cards, they skimmed the instructions, looking for changes.

Placement of an "R" in the left margin of a CITEXT-generated card denoted a revision. For example, following the accident at Narita, the CITEXT instruction for inspection of the engine pylon diagonal brace strut lugs was revised to add the ship identification of the seven NWA B-747 airplanes that require installation of a secondary retainer in the pylon aft diagonal braces. The "R" was seen in the margin of the revised cards.

The Safety Board investigation identified numerous problems with the CITEXT system. For example, certain tasks were duplicative, and two cards could call for opening a common access panel. When interviewed, mechanics said that they would write "N/A" (for Not Applicable) when work had already been performed. The Director of DC-10/B-747 Maintenance stated that he was aware that many people had a negative opinion of the CITEXT system and cited other problem areas. The most common CITEXT problems mentioned were conflicts with the airplane maintenance manual, and the lack of graphics and charts. Although the CITEXT system was said to have been developed to provide a single set of work instructions, the system required extensive coordination with the airplane maintenance manual.

According to NWA officials, at the time of the accident, the CITEXT system was undergoing modifications and improvements, and the improvements were reviewed by groups of users. Still, more than half of the workers interviewed for this investigation were critical of the CITEXT instructions. Many added that the current system was an improvement over the previous system. The Director of DC-10/B-747 Maintenance noted that since system acquisition, many CITEXT problems had been resolved through an established document change program and that one employee specialized in CITEXT changes. A group composed of managers, lead mechanics, and staff from NWA technical publications and maintenance programs met regularly to improve the system. NWA general inspectors were not included in the task force.

1.4.3 Maintenance Training

NWA maintenance officials stated that regular formal classroom training in NWA general maintenance procedures did not exist. General training was normally informal on-the-job training (OJT), although some employees reported having attended classroom sessions. Lead mechanics were responsible for the instruction of new employees assigned to them. OJT also had been used to teach mechanics and inspectors the subject materials contained in the GEMM for which each individual was responsible.

The airline had seven instructors assigned to B-747 and DC-10 maintenance training. The instructors conducted formal type-specific maintenance training courses for the B-747-100, 747-200, and 747-400. Mechanics assigned to the training were prioritized by training need and time in job assignment. A Director of Training position existed in the maintenance management. The position was vacant at the time of the accident, and the duties had been temporarily reassigned to an acting director.

On July 1, 1992, NWA had modified its maintenance training program and had implemented a program of 1-day familiarization training to be administered to newly hired mechanics. The training included the following topics:

(1) Company and maintenance organization; including a GEMM overview;

(2) Company rules and regulations;

(3) Airplane logbook, manuals, cards and forms;

(4) SCEPTRE (computerized maintenance tracking system) orientation;

(5) Hazardous materials; and

(6) Airframe/Powerplant familiarization.

1.4.4 Nonroutine Discrepancies

During the course of any maintenance activity, including inspections, the NWA maintenance system provided any mechanic or inspector with the ability to identify a "nonroutine" condition or work task. A numbered, red "Unit Inoperative or Removed" (NWA form OM 249) tag could be attached to the airplane in the vicinity of the system affected. The nonroutine card associated with this red tag contains a description of the condition identified, the location on the airplane, and space to record maintenance actions taken to correct the discrepancy. Nonroutine maintenance cards could also be generated for reasons that would not require the generation of red OM 249 tags.

The nonroutine card is comprised of three copies; two copies would be placed on the airplane's "work control board,"[3] and one copy would go into a separate security file. The mechanic taking the work assignment would decide, in accordance with the GEMM, whether the actions should be entered into SCEPTRE. Closure of shop paperwork, prior to return of the airplane to service, required accounting for each nonroutine card. One person noted that the multiple copies prevented missing closure of necessary work items, even though red tags were occasionally lost from the airplane during subsequent maintenance activities, such as airplane washing.

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[3]A work control board is a pin-on/grease pencil log board devoted to the airplane in work. The board allows control of the shop floor work flow, providing visibility to tasks in progress.

All of the maintenance and inspection personnel interviewed were asked to describe the red OM 249 tags and how to use the forms. The answers were not consistent with respect to how to use the forms, or when to complete them. The majority of mechanics stated that they would complete the form before compromising major components, such as the removal of strut parts. Some mechanics said that although they could do it by themselves, in practice they would bring in an inspector to initiate a red OM 249 tag. Still others said that the red OM 249 tag would be unnecessary if the work could be completed by the end of their shift.

1.5 "C" Check Details Relevant to the Engine Pylon Fittings

Prior to the scheduled nondestructive testing (NDT) inspection of the diagonal brace lugs and other work within the No. 1 pylon, NWA mechanics performing the "C" check were assigned to open the strut aft fairing doors and prepare the diagonal brace and other components for inspection. The written guidance they used for the NDT inspection was a CITEXT work control card titled, "INSP, 66, AD, #1NAC/PYL DIAG B." (See appendix A). Step 4 of this CITEXT card specifies the removal of the U-shaped secondary retention feature from the underside of the wing and the diagonal brace. The procedure does not call for the removal of the primary retention through bolt and washers. Removal of the secondary retention device would allow room to maneuver the transducer of the ultrasonic inspection device. A mechanic accomplished this step and also the next step on the card that specified a thorough cleaning of the diagonal brace lugs. His initials and employee number appear on the sign-off blocks of the CITEXT card for these steps. This individual stated that he did not remove the primary retention devices from the diagonal strut assembly.

The NWA inspector trained in nondestructive testing (NDT) was assigned to ultrasonically inspect both the No. 1 and No. 4 diagonal brace attach point fittings on the accident airplane as part of the "C" check. This inspector used the same CITEXT work cards as used by the mechanic who removed the secondary retainers.

This NDT inspector stated that when he performed his inspection on the airplane's pylon fittings, the primary retainers were installed; however, the secondary retainers had been removed per the CITEXT cards. He did not see a white cloth bag with retainer parts inside, such as the one found later. This individual stated that he had not requested the removal of the primary retainers for any reason in the previous 2 to 3 years because of a change in fitting design. He also stated that he had never experienced a false ultrasonic reading when testing with the primary retainers in place. The NDT inspector stated that he had not recognized that the secondary retainers were required on this airplane. He marked "N/A" in step 10 of the CITEXT instructions that stated, "Reinstall fuse pin secondary retainers at forward and aft lug locations if removed per step 4 above."

Two of the mechanics who closed the No. 4 engine pylon on February 19, 1994, were not experienced with engine and pylon work. Both of these mechanics were certificated airframe and powerplant (A&P) mechanics; however, they were normally assigned to work on the interiors of the airplanes. During the final close-up operation on the airplane, one of these mechanics found a white cloth bag containing the primary and secondary retainers for the No. 4 pylon (as opposed to the No. 1 pylon) attached to the side of the "batwing" door. Neither the mechanics nor their supervisors had considered looking inside the No. 1 pylon, they said.

An examination of the No. 4 engine pylon area by mechanics revealed that the required fuse pin retainers had not been installed on the No. 4 pylon diagonal brace. The retainers found in the cloth bag were then installed, and the airplane was subsequently rolled out for the operational check. The No. 1 engine and pylon had already been inspected and closed before the discovery of the uninstalled retainers on the No. 4 engine pylon. There was no attempt to reinspect the No. 1 pylon diagonal brace or to take long-term corrective actions at that time.

Preparations for the removal of the airplane from the hangar were accomplished on the night of Saturday, February 19, 1994. The "C" check inspection of the airplane was completed 4 days earlier than had been estimated by the work planning group. The airplane was rolled out for an operational check in the early morning hours on Sunday, February 20, 1994, and was released for revenue service on Monday, February 21, 1994.

During the investigation, another airplane undergoing pylon maintenance was examined. Red OM 249 tags were seen in the area of the diagonal brace fuse pins. One was tied to a hydraulic line located near the No. 4 pylon diagonal brace attachment point, and one red tag was also seen near the No. 1 engine access panel (the outboard batwing door). Most of the maintenance and inspection personnel interviewed reported that they did not remember seeing any red tags attached to the No. 1 pylon area on the accident airplane.

The work planning documents for the "C" check on the accident airplane did not call for removal of any diagonal brace aft fuse pin primary retainers. The NDT inspector stated that the primary retainer for the No. 1 diagonal brace was in place when the NDT inspection occurred. The Safety Board also learned that the No. 1 diagonal brace aft fuse pin (as opposed to the primary retainer) was removed during maintenance activity following the NDT inspection of the diagonal brace lugs. The mechanic that related this to the Safety Board stated that he was assigned to check for and remove rust in the area around the No. 1 pylon upper link. Although he found no rust in this area, he did note a migrated upper link bushing and generated a nonroutine work card for rework of the bushing. The discovery of the migrated bushing necessitated the removal of the No. 1 engine and then the upper link, so work on the upper link bushing could be accomplished. During reinstallation of the upper link, the aft diagonal brace fuse pin was removed to facilitate refitting of the upper link to the pylon, because of weight distribution within the pylon.[4] He said that neither the primary or secondary retention devices were in place when he removed and subsequently reinstalled the No. 1 pylon aft diagonal brace fuse pin. He closed by stating that because the diagonal brace fitting/pin system was only compromised by him for a few minutes, no nonroutine paperwork or red OM 249 tags need be generated. None of the mechanics interviewed stated that any maintenance of this sort was done on the No. 4 pylon upper link, or the No. 4 pylon aft diagonal brace.

1.6 Maintenance Personnel Information

1.6.1 Maintenance Personnel Hierarchy

The maintenance personnel in the NWA wide-body hangars have three intermediate levels of supervision. The first level of supervision is that of the lead mechanic (formally called a crew chief). They make specific job assignments and directly oversee the work of mechanics. Maintenance managers, the second level of supervision, supervise and oversee the work by one or more of the lead mechanics. The Director of B-747 and DC-10 Maintenance is in charge of the hangar maintenance staff, which includes the mechanics, lead mechanics and managers, but he has no authority over inspection personnel. The Director of B-747 and DC-10

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[4]This mechanic stated that normally the closer, forward diagonal brace pylon fuse pin would have been removed, but that in this case, the aft primary and secondary retainers had already been removed by someone else, thus simplifying his job.

Maintenance is also responsible for employee training, shop safety, and maintaining an acceptable level of performance of his subordinates and reports to the Vice President of Maintenance Operations. A Vice President of Technical Operations is above the Vice President of Maintenance Operations.

1.6.1.1 NWA Inspection Organization

NWA has a Vice President of Engineering, Inspection, and Quality Assurance. The Director of Central Inspection/Chief Inspector reports to the Vice President and is responsible for the inspection managers and individual inspectors.

1.6.2 Shop Shifts and Staffing Levels

NWA's hangars 5 and 6 at the Minneapolis/St. Paul International Airport (MSP) were dedicated to NWA's B-747 maintenance operations. Aircraft maintenance procedures were performed 7 days a week on three 8-hour shifts. The first shift started at 0648 and ended at 1548; the second shift operated from 1548 to 2248; and the third shift from 2248 to 0648. Maintenance technicians (mechanics) were permitted by union seniority to bid on the shifts they wanted to work.

The Director of B-747 and DC-10 Maintenance stated that 545 people work under his control. He said that 252 of the 545 people were assigned to the first shift. Concerning weekend shifts, he stated that there have been some shift coverage problems, and that on weekends 250 people work the first shift, 130 work the second shift, and 34 work the third shift. He also stated that overtime for personnel in January 1994 was 14 1/2 percent over a 40-hour work week, February 1994 was 20 percent, and, for the first 6 days of March, it was 6 percent. Due to less desire for weekend work, the maintenance and inspection staffs frequently did not work in their usual functions. Individuals worked with constantly changing crews and worked in different settings than they were accustomed.

1.7 The Physical Environment of Hangars 5 and 6

The Safety Board examined the physical environment of hangars 5 and 6. Both hangars have work stands (known as wing docks) located under the wings of B-747s, under the tail surfaces, and at other locations around the airplane. The wing docks in hangar 6 were constructed of scaffolding with plywood decking that provided openings for wing jacks and other maintenance equipment. Loose wooden planks were on the wing docks, some of which were laid across open areas to connect the wing dock to the engine stands, more than 8 feet above the concrete floor. At least one inspector expressed personal safety concerns when he had to rely on the wood planks between the docks to perform his inspections. He said that after becoming tired of climbing down from the wing dock and back up the engine stand, he reluctantly used the temporary wood bridges between the docks.

There were fixed lights on the wing docks to illuminate the underside of the wings and the airplane; however, many of the light fixtures were either covered with paint overspray and provided poor illumination, or were not in use. Mechanics were observed using portable work lights and flashlights when they were working on the undersides of the airplanes. One employee stated that hangar 6 had previously been used for painting airplanes, and that it resulted in paint overspray on the light covers. In contrast, the wing docks in hangar 5 were permanent fixtures that permitted the use of space below the stands. Light levels in the work areas of hangar 5 were higher than in hangar 6.

During the inspection of hangar 6 by Safety Board investigators, a No. 4 engine pylon from a B-747-400 undergoing maintenance had been removed and was placed on a floor stand located under the No. 4 engine position. Other parts removed from the airplane were also placed in racks for parts and on the hangar floor. A ladder stand was adjacent to the No. 4 pylon with a partitioned wooden box on the top step that contained fuse pins and retainers from the No. 4 pylon. The parts overfilled the partitioned areas, and the fuse pin bearing surfaces were resting against each other. On two separate shop visits, investigators observed this box in the same location.

Other stored parts were located on racks located in the hangar area. Part storage was different in different work areas. Some areas were neat, with parts clearly placed in an orderly fashion on the racks. However, as with the wooden box containing fuse pins from the subsequent airplane, storage of vital components was not the same in all areas.

1.8 Other Incidents and the Boeing Response

Migrations of upper link fuse pins or diagonal brace fuse pins have been reported on five occasions by several airlines prior to the NWA Narita accident. One of these resulted in an accident similar to this accident. The other four were discovered during routine maintenance. One other instance of pylon fuse pin migration has occurred since the Narita accident. All of these incidents were attributed to the improper assembly of the components during maintenance.

The pin migration incident that caused the earlier accident involved Air India flight 132 on May 7, 1990. In this incident, an upper link fuse pin fractured immediately after a harder-than-normal touchdown. The engine also rotated to the runway surface around the midspar fitting, as seen at Narita. In this instance, prior to the accident, the aft fuse pin on the diagonal brace had also migrated out of its fitting. According to the Indian investigation report, the fuse pin was found intact at the side of the landing runway with the retaining bolt and nut installed; however, the primary retaining caps were not installed. The Government of India presented the following cause of the accident in its final investigation report:

> The accident was caused due to the migration of the improperly installed diagonal-brace aft fuse-pin of the No. 1 engine from its fitting which substantially reduced the load carrying capability of the engine fittings resulting in failure of the upper-link forward fuse pin due to excessive loads on account of probably improper landing leading to a partial separation of engine and fire.

On July 5, 1990, following the Air India accident, Boeing issued Service Letter 747-SL-54-35, suggesting operators ensure that fuse pins are correctly assembled and recommended incorporation of the secondary retention devices at the earliest maintenance opportunity. Following the Narita accident, Boeing issued a revision to the earlier service letter (Service Letter 747-SL-54-35-A). This document stated:

> While the 747 nacelle strut upper link and diagonal brace load paths are redundant, the struts were not designed to be fully fail-safe with a member disconnected. The struts were designed for safe separation under conditions exceeding ultimate design loads. The struts have limited fail-safe capability for a detached upper link or diagonal brace. This capability exceeds normal operating loads. However, the fatigue life of the remaining member may be significantly reduced.

The service letter included advice to customers that all fuse pin installations must be correctly assembled and that established maintenance procedures should be adequate to account for all removals and reinstallations of the pins and retention hardware. It also recommended that operators incorporate the secondary retention devices at the earliest maintenance opportunity. No other corrective actions were initiated by Boeing or the FAA at that time.

Following the discovery of one more migrated fuse pin after the Narita accident, on August 26, 1994, Boeing issued Service Letter 747-SL-54-35-C.[5] This service letter reiterated the information contained in the earlier service bulletins on this issue. It also stated that the service bulletin requiring the inspection and replacement of diagonal brace fuse pins (SB 747-54-2153) will be revised by the first quarter of 1995 to include the part number callout in the removal and installation steps. This, Boeing states, will ensure parts accountability during installation.

1.9 FAA Oversight

The principal maintenance inspector (PMI) for NWA has held that position since 1985. He was not responsible for the maintenance oversight of other operators, and he was assisted by two assistant PMIs and six partial program managers (PPMs), one for each type of airplane in NWA's fleet. The PMI stated that he believed NWA was a "compliance-oriented" airline and that company management was professional and cooperative. He was of the opinion that the CITEXT system has improved overall maintenance at NWA, and that it had also made it easier for the FAA to monitor NWA maintenance activity.

The PPM for the NWA B-747 fleet had held that position for 5 months at the time of the accident. For approximately 5 years before he became the PPM for B-747s, he was the PPM for the NWA Airbus A-320 fleet of 50 airplanes. He stated that he often visits NWA hangars 5 and 6 to observe various maintenance operations, and, in fact, attempted to do so at least one night a week. He said that his surveillance also included weekend activity when he observes work accomplished during the inspections. He then followed the paperwork generated by the maintenance to compare work performed against work required. Part of this surveillance procedure was to compare the contents of the CITEXT-generated work cards with GEMM and maintenance manual requirements. There was, however, no formal program (outside of his real-time shop observations and

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[5]Service Letter 747-SL-54-35-B corrected two references in Service Letter 747-SL-54-35-A.

comparisons) to compare a general, random sampling of CITEXT-generated work cards with GEMM and maintenance manual procedures. He also stated that most of his inspections took place after a particular maintenance operation had been completed. In addition, he said that the FAA regional office established his work program, and required that at least 35 percent of his time be dedicated to actual airplane surveillance.

According to FAA personnel, routine surveillance, unless it was required for compliance with airworthiness directives or other specific tasks, did not include monitoring the preparation of work instructions, storage and the documentation of parts removed from airplanes (housekeeping), or audits of completed work.

1.10 Actions Taken by NWA Since the Accident

Since the accident at Narita, NWA has taken the following actions to preclude recurrence of the maintenance anomaly.

1. The NWA Central Engineering Division has revised all engineering orders that require the removal of engine strut fuse pin components. These engineering orders now contain a step that requires inspection signoff and that specifically address reinstallation of all fuse pin retention hardware.

2. The NWS Production Planning Division has accelerated accomplishment of the Boeing service bulletin concerning engine strut third generation fuse pin installation. All B-747 airplanes will have third generation pins installed by April 1, 1995.

3. The NWA Systems and Automation Division is in the process of replacing the CITEXT system with the AMI-Task system job instruction cards that include graphics. AMI-Task will be ready for B-747 periodic maintenance checks by September, 1995.

4. The NWA Technical Publications Division has revised OM-249 red tag procedures via a revision to the CITEXT cards concerning pylon strut removal, installation, and opening and

closing of the pylon to insure midspar fuse pin retainer installation.

5. The NWA Technical Operations Training Division has intensified technical training of mechanics throughout the NWA maintenance system. Also, in conjunction with the FAA, Boeing, and the IAM, NWA is implementing a Maintenance Error Decision Aid concept that addresses human factors principles in hangar work procedures.

2. ANALYSIS

2.1 General

The Safety Board examined NWA's overall maintenance practices and procedures, reviewed the airplane's "C" check records, and analyzed why the airplane was returned to service without the primary and secondary aft diagonal brace fuse pin retainers installed on the No. 1 engine pylon.

The Safety Board determined that the secondary retainer for the aft fuse pin on the No. 1 and No. 4 engine pylon diagonal brace had been removed, as required and directed by the CITEXT system, to permit NDT of the diagonal brace end fittings. The inspector who performed the NDT stated that he signed the paperwork, indicating that he performed the required tests, then further stated that he also signed N/A (not applicable) in the blocks that direct the reinstallation of the secondary retainers. The person(s), who removed the primary retainers, and the reasons for their removal, were not identified. The Safety Board could not determine why there were no nonroutine work cards generated or red OM 249 tags applied to the aircraft structure in the vicinity of the primary retainer, after its removal, as required by the GEMM. Although a red OM 249 tag could have been accidentally lost by washing the airplane or other maintenance, a mechanic performing nonroutine parts removal should have generated the nonroutine card paperwork to ensure that the removed parts (in this case the primary and secondary retainer set) were reinstalled and that the area was inspected. The security copy of both the nonroutine work card and the red OM 249 tag, in addition to redundant copies of both forms contained in the work control package, should have precluded the closing of the paperwork prior to the release of the airplane.

The evidence indicates that several important maintenance procedures were either not followed or were followed incorrectly during the maintenance and inspection of the airplane. On February 20, 1994, after all "C" check maintenance actions were considered to have been completed, the airplane was dispatched for revenue flights. After the airplane was returned to service, it completed 14 cycles without incident, prior to the accident flight. The diagonal brace aft fuse pin migrated out of the fitting at some point during the 14 flights, and the upper link fuse pin failed in overload during rollout at Narita.

2.2 Maintenance Procedures

2.2.1 General

The evidence indicates that several of the previously established procedures were either not followed or were followed improperly. They include:

GEMM procedures;

Organizing, describing, and tracking the performance of maintenance actions through a computerized system known as CITEXT;

Monitoring with CITEXT the completion of maintenance actions taken;

Application and prominent display of red OM 249 tags when systems were rendered inoperative or unserviceable; and

Requiring a general visual zonal inspection of the work area before closure.

2.2.2 Fuse Pin Retainers

A given B-747-200 airplane could have two different types of pylon retention fuse pins installed on the four engine pylons. The mechanic performing maintenance on the pylons would be unable to determine the particular pin installed by looking at the CITEXT card. Only by close inspection of the pin could he or she determine the particular generation of pin installed. In addition, only the second generation fuse pins had secondary retainers installed and required removal for inspection.

2.2.3 CITEXT Procedures

The CITEXT card relevant to this accident specified steps to be carried out to perform the ultrasonic inspection of the engine strut diagonal brace aft lugs to ascertain if crack indications were present. Step 4 of the procedure called for the removal of the secondary fuse pin retainer to allow access for the ultrasonic inspection. The CITEXT card did not direct the removal of the primary fuse pin.

However, the evidence suggests that both the secondary and primary fuse pin retainers were removed from the No. 1 and No. 4 engine pylons at some point. Only the last minute fortuitous finding of the fuse pin retainers near the No. 4 engine pylon prompted their reinstallation on that pylon.

None of the maintenance personnel that Safety Board investigators interviewed, including all who had worked on the No. 1 or No. 4 pylon diagonal braces, had knowledge of the person who had removed the primary fuse pin retainers from either diagonal brace. Consequently, the Safety Board was unable to identify the individual who had removed either primary retainer, the mechanic who had failed to reinstall the No. 1 diagonal brace primary or secondary retainer, or the specific reason why the primary fuse pin retainers were removed when such action was not specified in the CITEXT instructions. Neither could it be determined why red OM 249 work tags were not placed on the diagonal brace to indicate that a system was compromised.

The Safety Board noted the apparent compartmentalization of maintenance tasking in a large maintenance organization such as that of NWA. The mechanic, who removed the No. 1 pylon aft diagonal brace fuse pin for several minutes to facilitate reinstallation of the No. 1 pylon upper link, was not concerned that the pin was not retained in its fitting in any manner. He believed that the retaining device or devices had conveniently been removed for some valid reason by other mechanics already, that the brace/fitting/pin system was only compromised for a few minutes, and that he would return the system to its exact previous state. Therefore, in his mind, no nonroutine card needed to be generated, and no red OM 249 card needed to be attached in the diagonal brace area. Had he, or any one of his various supervisors, been more aware of the overall maintenance plan for the No. 1 pylon area, the existence of a retainerless fuse pin so late in the "C" check process might have been recognized as an anomaly, and this accident might not have occurred.

The Safety Board examined the quality of the instructions on the CITEXT card to determine how the wording on the CITEXT might have played a part in the accident. Although the relevant card in this accident was created for the maintenance to be performed on the airplane, as well as the particular day in which the maintenance actions were to be carried out, it did not specify the type of fuse pin present on the particular pylon or whether secondary fuse pin retainers were required to be present. Step 4 of the procedure called for the removal of the fuse pin secondary retainer "if installed."

This step is straightforward. If secondary retainers are present when the airplane arrives for maintenance, then they must be removed before NDT inspection of the fitting. However, the necessity for the reinstallation of the secondary retaining devices is not as obvious. The mechanic is required to perform several actions as part of step 10 of the CITEXT card. Nevertheless, these relatively simple actions required the application of different skills. The mechanic first had to examine the pin to determine the type that was installed. Based on this examination, the mechanic then had to perform the necessary maintenance action, as appropriate to the type of fuse pin retainer installed. No guidance was present on the card to help the mechanic determine the potential need for the secondary fuse pin retainer, or to assist in identifying which generation fuse pin was installed. Perhaps more important, no feedback was available to the mechanic to indicate whether his or her determination had been correct.

The mechanic who removed the No. 1 engine secondary fuse pin retainer prior to the NDT estimated that he had performed that task 50 to 100 times over a period of about 4 years. He had previously been employed 22 years performing aircraft maintenance in the U.S. Navy. He also displayed competence in the documentation of work and in the use of "nonroutine" documents. The Safety Board believes that his experience with the airline and with the Navy was sufficient to provide him with an appreciation for the need for full adherence to required maintenance action directions. His experience would not support the type of carelessness in reading and applying instructions that led to this accident, if indeed he removed and failed to reinstall the relevant fuse pin retainers.

NWA mechanics performed their maintenance according to directions on the CITEXT cards. According to NWA, information on the cards originated in the approved airplane maintenance manual and was tailored to the records of previous maintenance actions taken on each airplane. The CITEXT cards were meant to be used as work cards that "translated" procedures referenced in the airplane maintenance manual into a series of maintenance-related actions.

All of the mechanics that the Safety Board interviewed indicated that with CITEXT, they continued to refer to the maintenance manual. The potential for confusion was high among mechanics who were attempting to adhere to the GEMM, coordinate with the maintenance manual, and follow the CITEXT directions.

The Safety Board believes that NWA could have eliminated the potential for confusion among mechanics by clarifying the instructions on the CITEXT card in question. This could have been accomplished by stating on the card that the removal of the secondary fuse pin retainers is necessary only on specific pylons equipped with second generation fuse pins and supplying graphics on the card. Since the accident, NWA has addressed the potential for confusion over retainer types by modifying the text in the CITEXT according to the type of pin installed. Nevertheless, the Safety Board is concerned that the potential for confusion from unclear CITEXT directions may exist elsewhere in the NWA maintenance system. If so, mechanics could become confused by required maintenance actions and might perform an unnecessary action, as a mechanic did on the accident airplane. Therefore, the Safety Board believes that NWA and the FAA should review the NWA CITEXT system, and, where practical, require the modification of sections that refer to actions, components, or systems that are specific to particular airplanes to ensure that the maintenance action requested conforms to the maintenance action required for the specific airplane.

The No. 1 pylon aft diagonal brace primary fuse pin retainer was removed for some unknown reason, at some unknown time, during the "C" check. It was not reinstalled. The secondary retainer was removed in accordance with step 4 of the CITEXT card, but was not reinstalled, as required by step 10 of that card. Specifically, the mechanic was instructed, in part, to: "Reinstall fuse pin secondary retainer at forward and aft lug locations if removed per step 4 above." The Safety Board believes that the failure to reinstall the primary and secondary fuse pin retainers on the pylon of engine No. 1 was the result of a series of errors.

2.2.4 Red OM 249 Tag Procedures

NWA had implemented a procedure to prevent the very errors that led to this accident, but the procedure was not followed. Red OM 249 tags were to be prominently posted in the area in which systems were compromised. The red OM 249 tags were to be removed after the components had been reinstalled or the wiring or tubing had been reconnected. In this manner, mechanics and inspectors had a visual means to alert them when components were not in place and when work was not complete. The Safety Board believes that the red tag procedure is an excellent method, if used properly and consistently, to prevent the type of error that occurred on this accident. It can serve as an additional and highly visible method of alerting mechanics to the fact that maintenance action on a critical component had not been completed.

The investigation revealed several flaws in the application of the airline's red OM 249 tag procedures. Personnel had differing interpretations of the airline's red tag policy. Most of them appeared to understand that a red tag was to be displayed when a major or vital component or system had been compromised. However, the mechanic tasked with removing the secondary fuse pin retainer believed that the red tag was to be posted when specified on the CITEXT. Since the CITEXT card for this action did not call for posting a red tag, he did not post one. Further, it was unclear whether different mechanics would have considered the fuse pin retainers sufficiently critical to warrant the red tags. The evidence suggests that if a red OM 249 tag had been posted following the removal of the fuse pin retainers, someone would have noticed that the maintenance action had not been completed (at least the absence of the primary pin retainer would have been noted) and the accident could have been avoided. Therefore, the Safety Board believes that the failure of the mechanics to use red OM 249 tags following the removal of the fuse pin primary and secondary retainers, as well as the inadequacy of red tag training, was another in the series of errors.

The Safety Board notes that the OM 249 tags are red, a meaningful color in aviation. Red is primarily used to alert pilots or maintenance personnel to an unusual condition, and it stands out within the predominantly green, silver, and brown colors inside the B-747 engine pylon. Investigators noted that a few high strength fasteners within the pylon were highly conspicuous due to small areas of red, and that a prominent color might have stood out for the "OK to Close" inspector who stated that he was looking for obvious discrepancies.

The Safety Board also notes that the incident that occurred since the Narita accident indicate that the potential exists for the omission of both the primary and secondary retainers on reassembly, in spite of the warning message issued by Boeing to operators. The common element between the accidents and incidents has been the maintenance personnel involved. Since the primary retainers independently hold the fuse pins by covering them, the Safety Board believes that making the semi-hollow fuse pin interiors that are normally covered by the primary retainers conspicuously red (or some other conspicuous color such as dayglo orange) would alert maintenance personnel to the omission of the retainers. This would not require the removal of fuse pins from the airplane and could be accomplished as access becomes available. Although the third generation pins are supposed to eliminate the need for secondary retainers, the Safety Board believes that an interim addition of red paint would add a level of safety and that it should be recommended to all operators of B-747 airplanes.

2.2.5 Nondestructive Testing

CITEXT step 6 called for an ultrasonic or NDT inspection of the diagonal brace lugs to ascertain the presence of crack indications. If evidence of cracks were found, step 7 directed the inspector to proceed to step 8. If no cracks were found, the inspector was to put "N/A" (not applicable) in the appropriate boxes of steps 8 and 9, and the mechanic was to go to step 10. The inspector who performed the ultrasonic inspection found no cracks, and appropriately marked N/A adjacent to steps 8 and 9. However, the evidence indicates that he then proceeded to inappropriately mark N/A adjacent to the remaining steps 10 and 11. Step 10 called for the reinstallation of the secondary fuse pin retainer. Consequently, the Safety Board believes that the inspector's inappropriate completion of the CITEXT card was another in the series of errors.

The inspector who performed the ultrasonic inspection performed such inspections almost exclusively. The evidence from this accident suggests that in his routine, he properly focused on the item to be ultrasonically tested but paid less attention to the accompanying paperwork. As a result, he did not notice, and he was not expected to notice, whether the secondary fuse pin retainer had been removed. Following his inspection, his routine was, again appropriately, to mark the CITEXT cards according to what he had found.

The NDT inspector told Safety Board investigators that he marked N/A for steps 8 and 9. He made no mention of marking N/A for the remaining steps, although the marking on the card was clearly similar. The Safety Board was unable to determine why he inappropriately marked N/A adjacent to those steps of the CITEXT card. The evidence does suggest that the inspector merely completed the card inattentively. Overlapping work tasks identified on multiple cards were normally marked out with an "N/A". Therefore, an unquestioning acceptance of the NDT inspector's N/A marks (in the wrong blocks) could have gone unnoticed. The circumstances of this accident illustrate the importance of devoting the necessary attention to accompanying "paperwork" as well as performing the tasks specified by such paperwork. Because of similar occurrences of fuse pin migrations at other airlines, one of which was subsequent to the Narita incident and the Boeing service letter, the Safety Board is concerned that similar problems continue to exist at other airlines. Therefore, the Safety Board believes that the FAA should inform other airlines operating under 14 Code of Federal Regulations (CFR) Part 121 of the circumstances of this accident, and urge them to implement corrective actions, where necessary, to prevent the maintenance program deficiencies that were noted in this accident.

2.2.6 The "OK to Close" Inspection

NWA had implemented a final means to identify disassembled components or systems that had not been reassembled. The "OK to Close" inspection was performed before open doors or panels could be closed. In this inspection, open doors or panels could not be closed until an inspector performed a general, visual, and zonal inspection of the work area.

The inspector stated that signing off of the "OK to Close" inspection indicated that he had examined the work area, found no red OM 249 tags, or any other obvious discrepancies, and signed off on the work that had been performed on that pylon as completed. He qualified his description of the "OK to Close" inspection by stating that it was a quick area inspection for rags and previously identified problem areas. Then, as he was about to approve the work on the No. 4 engine, maintenance personnel found the No. 4 engine fuse pin retainers. Neither he, the maintenance personnel, nor the on-site maintenance managers believed that finding these components near, but not in, the pylon suggested that similar retainers could have been missing from the No. 1 pylon. After the reinstallation of the retainers on the No. 4 pylon, the work on the airplane was considered completed, and the airplane was placed into service. If the inspector or a maintenance manager had gone back and noticed that the fuse pin retainers were missing from the pylon of the No. 1 engine, it is likely that the retainers would have been correctly installed.

The inspector completed and approved the "OK to Close" inspection of the pylon about 0600 on February 20, 1994, at the end of a night shift, on the sixth full night of work, following what was to have been a regularly scheduled 5-day week. NWA personnel indicated that on that night of the week, the number of maintenance personnel on duty was at its lowest for the week. NWA mechanics were consistent in denying that they felt pressure to rush a maintenance action or inspection. Maintenance personnel were aware, however, that the company was expecting the work on the airplane to be completed that night. He indicated that he worked about twice as hard that night, or performed about twice the inspections, in comparison with what he normally did during the week. Moreover, because of the shortage of personnel, he and one other inspector were expected to work on two B-747 airplanes in both hangars 5 and 6. He indicated that on that night, he constantly shifted between the two hangers. This most likely added to his sense of feeling pressured, and possibly to some fatigue by the end of the shift, when he performed the inspection in question.

2.3 Maintenance Training

The evidence indicates that NWA's method of training in the GEMM, CITEXT, and application of the red OM 249 tag procedure was less than systematic. The mechanics who worked on the airplane learned the method informally, through OJT from more experienced maintenance personnel. As a result, the level of understanding of the red tag procedure was largely influenced by the quality of training a mechanic had received from his or her OJT instructor. Consequently, multiple interpretations of the system, including some that were not in accordance with the GEMM, prevailed.

Airlines operating under the provisions of 14 CFR Part 121 are required to adhere to Part 121.375, which states:

> Each certificate holder or person performing maintenance or preventive maintenance functions for it shall have a training program to ensure that each person (including inspection personnel) who determines the adequacy of work done is fully informed about procedures and techniques and new equipment in use and is competent to perform his duties.

On July 1, 1992, NWA had modified its maintenance training program and had implemented a program of 1-day familiarization training to be administered to newly hired mechanics. The training included the following topics:

GEMM orientation;

Company and maintenance organization;

Company rules and regulations;

Aircraft logbook, manuals, cards and forms;

SCEPTRE (computerized maintenance tracking system) orientation;

Hazardous materials; and

Airframe/powerplant familiarization.

According to NWA, red tag procedures were to be discussed during the session on aircraft logbook training. With one exception, the mechanics who were interviewed had been hired before this training was initiated. Therefore, nearly all of them had been taught about red OM 249 tags through OJT. As a result, NWA maintenance personnel, who worked on the accident airplane, did not uniformly understand the conditions under which the red tags were to be used and had a variety of interpretations of the procedure. A common perception was that the red tags were an available, but not a required, procedure.

Nevertheless, the Safety Board believes that this procedure, irrespective of its perceived informality, was an important part of the process of ensuring that critical maintenance procedures were performed and completed without error. Because of its importance, the Safety Board believes that NWA should have formalized the red OM 249 tag procedure and ensured that all mechanics understood it and implemented it properly and consistently.

The Safety Board has previously expressed its views on the importance of proper aviation maintenance training in its investigation of the accident involving an Aloha Airlines B-737-200,[6] that lost part of its fuselage in flight. As a result of that investigation, the Safety Board recommended that the FAA:

> A-89-55
> Revise the regulations governing the certification of aviation maintenance technician schools and the licensing of airframe and powerplant mechanics to require that the curriculum and testing requirements include modern aviation industry technology.

In response to that recommendation, the FAA substantially revised and modernized the curricula required of schools certificated under Federal Aviation Regulations (FAR) Part 147, where many aviation maintenance technician students are being trained. The final rule for this revision of curricula is dated June 29, 1992. Based on these amendments to the regulations for certificating aviation maintenance technician schools, on February 22, 1994, the Board classified A-89-55 "Closed--Acceptable Action."

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[6]Aircraft Accident Report--"Aloha Airlines, Flight 243, Boeing 737-200, N73711, Near Maui, Hawaii, April 28, 1988." (NTSB/AAR-89/03)

During its investigation of this accident, the Safety Board has learned that the FAA also intends to modify the requirements for the certification of airframe and powerplant (A&P) mechanics to create a separate category of A&P certificate to be required of mechanics who perform maintenance on aircraft certificated under 14 CFR Part 25. A Notice of Proposed Rulemaking (NPRM) was promulgated to that effect, and comments were due on October 12, 1994.

2.4 Maintenance Working Environment

The Safety Board believes that the "OK to Close" inspector was hindered considerably by the environment of the pylon area. He indicated, for example, that the combination of location of the scaffolding (at a level just below the underside of the wing that forced him into unusual and uncomfortable physical positions) and inadequate lighting from the base of the scaffolding up toward the pylon, hampered his inspection efforts. Moreover, the underside of the pylon was illuminated by portable fluorescent lights that had been placed along the floor of the scaffolding. These lights had previously been used in areas where airplanes were painted, and, as a result, had been covered with the residue of numerous paint applications that diminished their brightness. These factors combined to cause the inspector to view the fuse pin retainers by holding onto the airplane structure with one hand, leaning under the bat wing doors at an angle of at least 30°, holding a flashlight with the other hand pointing to the area, and moving his head awkwardly to face up into the pylon area. Concerning other work areas around the airplane, the inspector admitted that he felt apprehensive because of the lack of protection against a person falling from the scaffolding, a height of about 8 feet above the concrete floor.

In its investigation of the previously cited accident involving the Aloha Airlines Boeing 737-200, the Safety Board addressed human factors-related deficiencies similar to those noted in this accident; that is, in the environment in which visual inspections were being carried out. In that investigation, the Safety Board noted the challenges that these deficiencies presented to the performance of visual inspections and the resultant diminished effectiveness in detecting "errors" during such inspections. As a result of its investigation of that accident, the Safety Board recommended that the FAA:

> <u>A-89-57</u>
> Require operators to provide specific training programs for maintenance and inspection personnel about the conditions under

> which visual inspections must be conducted. Require operators to periodically test personnel on their ability to detect the defined defects.

In partial response to that recommendation, the FAA's Office of Aviation Medicine performed a human factors evaluation of maintenance-related issues, such as lighting in maintenance work areas and the scheduling of rest time for mechanics. The final report was entitled "Human Factors Evaluation of the Work Environment of Operators Engaged in the Inspection and Repair of Aging Aircraft."

The Safety Board believes that many of the FAA's efforts in response to the maintenance and inspection issues identified in the Aloha Airlines accident were positive and served to increase the understanding of contemporary human factors issues that affect the quality of aircraft maintenance. For example, following the completion of the final report noted above, the FAA sponsored an on-going effort to address human factors issues in maintenance. Part of that effort was a multiphase study[7] that directly addressed many of the issues relevant to this accident. For example, Phase I of the report, in identifying factors that affect the ability of inspectors to detect defects, stated:

> The factors affecting the conspicuity of a defect are defect size, defect/background contrast, and lighting intensity. The latter two are functions of the lighting and can be improved without changing the aircraft design. Defect/background contrast is a function of the angles between the inspector's eye, the defect, and any light sources. In general, an adequate level of illumination needs to be provided at the inspection point, with levels of 500 to 1000 lux typically recommended. However, the distribution of light is at least as important as its intensity. Of particular concern is that in inspecting partially hidden areas (e.g., inside door panels), the lighting used to illuminate the defect may cause glare from surrounding surfaces. Carefully designed combinations of general area lighting, portable area task lighting, and localized spotlighting need to be produced.

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[7]"Human Factors in Aviation Maintenance Phase I: Progress Report." Galaxy Scientific Corporation, 1991 (FAA report No. DOT/FAA/AM-91/16, pp. 78 and 79).

The evidence indicates that the human factors-related impediments to the effective performance of maintenance/inspection procedures that the Safety Board found nearly 6 years ago in its investigation of the Aloha Airlines accident, and that the FAA identified 2 1/2 years after the accident in its study of human factors issues in aviation maintenance, were also present in the NWA maintenance program.

In addition to its response to Safety Recommendation A-89-57, the FAA also stated that it would issue an airworthiness bulletin to its principal maintenance inspectors (PMIs) to require them to ensure that their assigned operators include specific training and testing in maintenance/inspector training programs that address the problems associated with performing visual inspections. Pending receipt of the published airworthiness bulletin, the Safety Board classified the FAA's response "Open--Acceptable Response" on February 22, 1994.

The circumstances of this accident suggest that the FAA has adequately studied many of the critical human factors issues in aviation maintenance but that the implementation of many of the positive findings from these studies have not yet been accomplished. Additional training of maintenance and inspection personnel, while beneficial, will not mitigate the problems of inadequate lighting and potentially hazardous scaffolding where visual contact with the area to be inspected is difficult or the immediate environment carries with it personal risk. Therefore, the Safety Board believes that the FAA should issue a directive to 14 CFR Part 121 and Part 135 air carrier PMIs instructing them to have their assigned carrier(s) conduct inspections to identify human factors-related impediments to the effective performance of maintenance and inspections, such as inadequate lighting and potentially hazardous scaffolding, and require the carriers to correct those deficiencies.

In addition, the lack of an organized method of storing parts removed from airplanes prevented the physical presence of the pins from alerting personnel to an error. The storage of parts was largely left to the lead mechanics, some of whom were more fastidious than others. If a location had been provided and habitually used for the No. 1 pylon retainers, they would have been visible after closure of the pylon. Instead, the parts were found behind a board on the wing dock. In hangars and work areas that perform repetitive inspections or other maintenance activities, the Safety Board believes that an organized means of storage must be provided to maintenance personnel and that personnel must use those facilities.

3. CONCLUSIONS

3.1 Findings

1. Maintenance and inspection personnel who worked on the airplane were properly certificated to perform the required maintenance and inspections.

2. Maintenance and inspection personnel who worked on the airplane were not adequately trained and qualified to perform the required maintenance and inspection functions. Critical functions had been taught by on-the-job training and were not standardized or formalized in an initial or recurrent training program.

3. The mechanic who removed and failed to reinstall the No. 1 pylon aft diagonal brace primary retainer could not be identified.

4. The inspector who performed the nondestructive testing inspection of the No. 1 pylon diagonal brace fitting properly completed the inspection, but he improperly signed off on several subsequent steps of the centralized interactive text system (CITEXT) instruction card. This could have led other maintenance and inspection personnel to interpret that the maintenance actions on the fuse pin retainers on engine No. 1 had been completed when they had not.

5. The "OK to Close" inspection of the pylon area was hampered by inadequate lighting and perceived dangers of the scaffolding.

6. The CITEXT used by Northwest Airlines was inadequate because it lacked the pertinent information contained in the FAA-approved maintenance manual, it did not follow Northwest Airlines' GEMM policy, and it did not contain specific instructions for actions, components, or systems that were specific to the B-747 No. 1 engine pylon.

7. Mechanics and inspectors of Northwest Airlines did not adequately understand the application of the CITEXT and red OM 249 tag systems for critical maintenance items.

8. Maintenance supervisors and managers of Northwest Airlines failed to ensure that the work practices of the mechanics and inspectors were conducted in accordance with the approved maintenance manual.

9. The work environment for the heavy maintenance of the airplane was inadequate and contributed to an error-producing situation for the workers.

10. The lack of adequate and organized storage of removed parts contributed to the failure to reinstall the fuse pin retainers.

11. FAA oversight of the maintenance facility at Northwest Airlines failed to detect deviations in red OM 249 tag procedures.

12. FAA inspectors failed to apply FAA-developed human factors elements and allowed an inadequate work environment in the hangar to exist.

Appendix 3 Comment of the Accredited Representative of United States of America for the draft final report (Theletter from the Accredited Representative)

National Transportation Safety Board
Washington D.C. 20594
October 21, 1996

Mr. Yoshiro Nakatsuji
Investigator-In-Charge
Ministry of Transport
Aircraft Accident Investigation Commission
2-1-3, Kasumigaseki, Chiyoda-ku
Tokyo 100, Japan

Dear Mr. Nakatsuji:

Thank you very much for the opportunity to review your draft final report concerning Boeing 747-251B, N637US. I apologize for not responding sooner, but I have been involved in the loss of TWA Flight 800 since July.

The report is very thorough and we agree with the proposed probable causes as written. We have no other specific comments concerning the draft report. I have taken the liberty to make one or two suggestions concerning alternate choices of a few words. Use these suggestions as you wish.

Sincerely,

Robert Benzon

Robert Benzon
U.S. Accredited Representative