AIRCRAFT ACCIDENT INVESTIGATION REPORT

Northwest Airlines
Boeing 747-400, N663US
New Tokyo International Airport
September 19, 1991

Aircraft Accident Investigation Commission
Ministry of Transport

September 24, 1993

(Tentative Translation from Original in Japanese)

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ATTENTION

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This brochure is a translation of the original report "Aircraft Accident Investigation Report on Northwest Airlines N663US, Boeing 747-400" 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 words, substance of contents, or context in any part of this English version.

Abbreviations used in this report are as follows

AC	Alternating Current
ACC	Airtrafic Control Center
AD	Airworthiness Directive
ADC	Air Data Computer
ALT	Altitude
APU	Auxiliary Power Unit
ASAS	Analysis Surface of Asia
ASCTU	Air Supply Control and Test Unit
BLD	Bleed
BMS	Boeing Material Standard
BTB	Bus Tie Breaker
BTL	Bottle
C	Centigrade
C1	Category 1
CAS	Computed Air Speed
CMC	Central Maintenance Computer
CU	Cumulus
CVR	Cockpit Voice Recorder
DC	Direct Current
DFDR	Digital Flight Data Recorder
DISC	Disconnect
EEC	Electronic Engine Control
EICAS	Engine Indicating and Crew Alerting System
ELEC	Electric
ENG	Engine
F	Flight Level
FAA	Federal Aviation Administration
FAR	Federal Aviation Reguration
FCU	Flap Control Unit
FMC	Flight Management Computer
GCB	Generator Circuit Breaker
GCR	Generator Control Relay
GCU	Generator Control Unit
GEN	Generator
hPa	hect Pascal
IDG	Integrated Drive Generator
IFR	Instrument Flight Rule
ILES	Inboard Leading Edge Station

ILS	Instrument Landing System
INT	Intermittent
JETT	Jettison
JST	Japan Standard Time
KVA	Kiro Volt Ampere
L	Left
LE	Leading Edge
LO	Low
LP	Loop
MAC	Mean Aerodynamic Chord
MEL	Minimum Equipment List
MHz	Megaherts
MIL	Military
MULT	Multiple
NAC	Nacelle
NAI	Nacelle Anti-Ice
NFDE	Non Flight Deck Effect
No.	Number
OVHT	Overheat
PA	Passenger Adress
PFD	Primary Flight Display
PROX	Proximity
psi	Pound Square Inch
psia	Pound Square Inch Absolute
QTY	Quantity
R	Right
REV	Reverser
Rev.	Rivision
SB	Service Bulletin
SL	Service Letter
ST	Stratus
SYS	System
TCD	Ministry of Transport, Civil Aviation Bureau, Directive
UTC	Co-ordinated Universal Time
VHF	Very High Frequency
VLV	Valve
VM_o	Velocity Maximum Operation
WAI	Wing Anti-Ice
X FEED	Crossfeed

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1 Progress and Process of Aircraft Accident Investigation

1.1 Summary of the Aircraft Accident

N663US, a Boeing 747-400, of Northwest Airlines departed New Tokyo International Airport for New York J. F. Kennedy International Airport about 0905 hours Universal Co-ordinated Time (1805 hours Japan Standard Time) on September 19, 1991. At about 0921 hours Universal Co-ordinated Time (1821 hours Japan Standard Time) when the aircraft was passing an altitude of approximately 26,000 ft during climb over the Pacific Ocean approximately 90 nautical miles east of New Tokyo International Airport, several messages to indicate malfunction of systems were displayed on instruments in the cockpit, and also malfunctions occurred to some systems, and therefore, the aircraft declared an emergency, and turned back for New Tokyo International Airport.

After fuel dumping was carried out, the aircraft made an emergency landing at the airport about 1031 hours Universal Co-ordinated Time (1931 hours in Japan Standard Time). In landing roll after touch-down, as well as at the time the aircraft came to a stop on a taxiway, fire occurred near the upper portion of No.2 engine pylon strut. About 1036 hours Universal Co-ordinated Time, an emergency evacuation was conducted on the taxiway for 294 passengers and a crew of 21, a total of 315 persons, in which occasion eight passengers were seriously injured in the evacuation

1.2 Outline of Aircraft Accident Investigation

1.2.1 Organization for Accident Investigation

1.2.1.1 On September 19, 1991, the Aircraft Accident Investigation Commission appointed the investigator-in-charge and six other investigators for investigation of this accident.

Alteration of the investigator-in-charge was made on April 1, 1993 in accordance with a personnel reshuffle.

1.2.1.2 Participation in accident investigation of related foreign governments

The accredited representative of the United States of America and his advisors participated in this investigation.

1.2.2 Period of Investigation

September 20～24, 1991	Investigation at accident site
Oct. 4,5 and 14, 1991	Investigation of aircraft, etc
Sept. 24, 1991～ May 29, 1992	Readout from CVR
Oct. 3 and 4, 1991	Readout from DFDR
Oct. 20～25, 1991	Readout from CMC

1.2.3 Hearing of comments of cause-related personnel

Hearings from them were conducted.

2 Factual Information

2.1 History of the Flight

N663US, a Boeing 747-400, of Northwest Airlines departed New Tokyo International Airport (hereinafter referred to as "Narita Airport") in a shower attendant on a typhoon for New York J. F. Kennedy International Airport as its Scheduled Flight 18 at 0905 hours Universal Co-ordinated Time (1805 hours in Japan Standard Time)(hereinafter, unless otherwise noted, time is represented by Universal Co-ordinated Time which is described as UTC) on September 19, 1991, with a flight crew of four, a cabin crew of 17 and 294 passengers (including 5 infants), 315 persons in total on board.
The flight plan of the aircraft filed to New Tokyo Airport Office, Civil Aviation Bureau, Ministry of Transport (hereinafter referred to as "New Tokyo Airport Office") was as follows:

Flight Rule: IFR, Destination: New York J. F. Kennedy International Airport, Initial Cruising Speed: 524 knots, Initial Cruising Altitude: F290, Route: CVC (Choshi), OTR11, KAGIS, A590, PABBA -- (rest omitted)-- Estimated Time Enroute: 11 hours 41 minutes, Alternate Airport: Washington Dalles International Airport

According to statements of the crew, records of flight data recorder and the central maintenance computer, the flight conditions thereafter were as follows:

After takeoff, the aircraft continued climb normally. In the vicinity of Choshi flight was conducted so as to evade a heavy rain area which was recognized on radar display. On passing this area (at an altitude of approximately 14,000 ft), the aircraft encountered light to moderate turbulences at times. When approaching KAGIS, the aircraft was cleared out of clouds at an altitude of approximately 24,000 ft and brought into the on-top condition.

About 0921 UTC, approximately 16 minutes after takeoff, when the aircraft was passing an altitude of approximately 26,000 ft during climb to the assigned Flight Level 330 at a CAS of approximately 300 knots over the Pacific Ocean approximately 90 nautical miles east of Narita Airport, many messages involving messages on malfunctions of systems relating to No.1 engine were displayed on the Engine Indicating and Crew Alerting System (hereinafter referred to as "EICAS"), and moreover at almost the same time, various malfunctions occurred.

Major EICAS messages displayed were as follows:

(1) Left Wing Bleed Duct Leak

《BLD DUCT LEAK L》

(2) No.1 Generator Trip

《ELEC GEN OFF 1》

(3) Flap System Inoperation of Primary Pneumatic Mode

《FLAPS PRIMARY》

(4) No.1 Engine Nacelle Overheat

《OVHT ENG 1 NAC》

(5) Flap System Inoperation of Primary Pneumatic Mode

《FLAPS DRIVE》

Around the time these messages were displayed, the leading edge flap expanded display was shown on EICAS indicating that the position sensor of the midspan and outboard group of left wing leading edge flaps failed and also that the inboard and the midspan group of right wing leading edge flaps came to a stop in the in-transit condition. In addition, "REV" in amber was displayed on EICAS indicating that No.1 engine thrust reverser was unlocked. However, according to the flight crew, neither yawing nor buffet was rècognized. After malfunctions occurred, the flight crew took necessary corrective actions or make a search for the EICAS messages and system malfunctions. To secure No.1 hydraulic system No.1 engine was not shut down, reduced to "idle", and was used as thrust as necessary. Furthermore, the alternate captain and the alternate copilot who had been in the cockpit assisted the captain and the copilot.

After malfunctions occurred, further climb was suspended and the aircraft was in a level flight at an altitude of approximately 27,000 ft for approximately 2 minutes. The captain declared an emergency about 0924 UTC to the Tokyo Area Control Center(Tokyo ACC), and initiated descent to an altitude of 10,000 ft with a clearance obtained. Descent was made with the speed brake at a CAS of approximately 300 knots.

The autothrottles had been in use during climb, but about 0923 UTC they were disconnected by the flight crew to maintain the climb power because an abnormal move of the throttle levers to retard to the idle position was indicated. The autopilot was used after past 0922 UTC, but it was disengaged by the flight crew because a malfunction occurred about 0923 UTC. However, the autopilot returned to normal later on, and was used from about 0938 UTC until before landing.

Moreover, the maximum speed bar on the speed indicator of the Primary Flight Display (PFD) lowered to 260 knots and when the aircraft was decelerated the maximum speed bar and the minimum speed bar came closer to and sometimes overlapped each other, and the stick shaker became activated 5 times in total about the time a descent was initiated from the level flight at approximately 27,000 ft (a period from about 0923 UTC to about 0924 UTC).

After about 0921 UTC when a series of malfunctions occurred, the auto-control of cabin pressurization system became inoperative, and the cabin altitude and temperature began to increase. Then the caution message 《CABIN ALT AUTO》 indicative of failure of the auto-control was displayed on EICAS. The cabin altitude continued to increase during descent to the altitude of 10,000 ft and exceeded 10,000 ft during the period of about 0927 UTC to about 0929 UTC, with the result that the master warning and the cabin altitude warning became activated and the flight crew had an oxygen mask on. The cabin altitude increased temporarily to approximately 11,300 ft. Thereafter the outflow valve was contolled manually, and after 0928 UTC the cabin altitude turned reversely to decrease, and down to approximately minus 3,800 ft about 0943 UTC. (However, indication on EICAS is limited to down to minus 1,100 ft) Thereafter the cabin altitude repeated a small variation up and down several times at approximately minus 4,000 ft. The flight crew stated that the cabin pressurization system was being manually controlled, but pointers of the instrument to indicate positions of the outflow valves were stuck at "1/8 open" for the left and at "full close" for the right.

At the time the aircraft, continuing descent, reached approximately 60 nautical miles east of KAGIS (approximately 180 nautical miles east of Narita Airport), the captain decided to return to Narita Airport, and began turn-back about 0930 UTC for Narita Airport with a clearance obtained from Tokyo ACC.

After descent to 10,000 ft, fuel dumping was started from about 0931 UTC while making a level flight over ocean in order to reduce the aircraft weight to the maximum landing weight (630,000 lb). However, due to malfunction of the left wing fuel jettison system, as much as 50 minutes was needed before it was finished about 1023 UTC when the aircraft was passing 6,000 ft in a further descent from 10,000 ft.

About 1010 UTC, the aircraft requested arrangement of emergency vehicles to Approach Control of the New Tokyo Airport Office (Narita Approach).

During this period, cabin attendants were informed by the flight crew that the aircraft was returning to Narita Airport for emergency landing due to systems malfunction, together with necessary instructions. The flight crew made also a cabin announcement to that effect for passengers.
Cabin attendants made briefing on emergency landing and evacuation procedures to passengers.

Flap position 25 was used for landing, and approach speed was 180 knots at the end of runway, 20 knots higher than usual, because malfunction of the leading edge flaps had been recognized.

The aircraft landed on Runway 34 of Narita Airport. All 4 engines were used as usual at the time of landing. However, as to thrust reversers, No.1 engine was not used, No.2 and No.3 engine were used as usual, and No. 4 engine at near idle thrust. About 1032 UTC, the aircraft, while landing roll on the runway in the vicinity of the crossing with Taxiway A3, received a report that "Left engine fired" from Airport Control Tower of New Tokyo Airport Office (Narita Tower) who recognized fire near the left engine; almost at the same time the flight crew also recognized the fire on the left side of the aircraft. Since malfunction relating to No. 1 engine had been displayed on EICAS, the flight crew immediately shut down No.1 engine, and discharged extinguisher to the engine. The fire was extinguished once. The aircraft cleared off the runway, entered Taxiway A through Taxiway A2, came to a stop in the vicinity of the crossing with Taxiway P1, and requested a tug.

About 1035 UTC fire vehicles which had followed the aircraft recognized that fire occurred again from near No.2 engine, and the aircraft was informed of it through the control tower. The flight crew also recognized flames of the fire, the captain shut down No.2 engine and discharged extinguisher. The fire vehicles discharged extinguisher around No.2 engine. The tower advised an emergency evacuation from the right side. The cpatain, who had also confirmed the fire flames on the left side of the aircraft, decided to make an emergency evacuation from the right side. The fire was extinguished about 1036 UTC.

About 1036 UTC emergency evacuation was directed, and No. 3 and No. 4 engine were also shut down.

In the dark of night and in the shower affected by a typhoon which was passing, the emergency evacuation was carried out using escape slides from R1, R2, R4, R5 doors on the right side as well as L1 door on the left side, and time was required to open doors, because the cabin had not been depressurized at the time the emergency evacuation was directed with a cabin pressure of approximately 2.6 psi(pound/square inch) higher than the outside atmosphere.

In this emergency evacuation, out of 315 persons consisting of 21 crew members and 294 passengers, 8 passengers were seriously, and 38 passengers slightly injured.

About 1140 UTC the aircraft was removed by a tug to the parking area (Spot 313) from the taxiway where the emergency evacuation was conducted. About 1301 UTC fire occurred near No.2 engine when a mechanic of the company connected external power in order to unload passenger baggage left in the cabin, but the fire was immediately put off. (see Attached Figs. 2, 8 and 9)

The runway of the airport was closed from 1031 UTC to 1052 UTC due to the emergency landing of the aircraft, and three of estimated arrivals changed the destination to and landed at the other airports within Japan.

2.2 Injuries to Persons

Out of 315 persons on board of crew and passengers, 8 passengers were seriously, and 38 passengers slightly injured.

2.3 Damage to Aircraft

2.3.1 Extent of Damage

The aircraft was substantially damaged.

2.3.2 Damage to Aircraft by part

Damage to each part of the aircraft was as follows: (see Attached Figs 5 ～ 7 and Photos. 1～6)

(1) Panel (outer skin)

* Access panel(No.511BB) on the wings undersurface inboard of No.2 engine pylon strut: burned, and the blowout panel: separated (the said blowout panel is designed to separate by a differential pressure of 2.5 psi)

* Access panel (No.511CT) on wing's upper surface as well as the inside of the fixed panel adjacent thereto: burned

* No. 2 engine pylon strut fairing panel (inside): burned

(2) Structural Parts

* Left and right skate angle of No.2 engine pylon strut: deformed by heat
* Web stiffener of No.2 engine pylon strut: deformed by heat
* Wing leading edge rib at inboard leading edge station (ILES)662.5: burned

(3) Inside of Left Wing Leading Edge at the upper portion of No. 2 engine pylon strut (between ILES630~693)

* No.2 engine fuel feed pipe: damaged (hole)
* No.1 generator feeder cable: damaged (cavity)
* No.2 engine fuel feed pipe
  clamp bolt: fractured,
  block: burned
* Wire bundles: burned
* Piping for fire extinguisher for No.1 and No.2 Engine: melted
* Wires of electric motor for driving leading edge flaps: burned

(4) Engines

No fire occurred on engines.

2.4 Damage to Other than Aircraft

None

2.5 Crew Information

2.5.1 Flight Crew

(1) Captain: Male, Aged 46

Airline Transport Pilot License	acquired on March 22, 1982
Type Rating Boeing 747-400	acquired on July 27, 1989
	(latest revision July 31, 1991)
Class 1 Medical Certificate	
	issued May 29, 1991 (valid until Nov.30, 1991)
Total Flight Experience	15,920 hours
Flight Experience on the type	973 hours 28 minutes
Flight Time in last 90 days	185 hours 58 minutes
Flight Time in last 30 days	41 hours 05 minutes
Rest period before the flight	21 hours 13 minutes

Note: The captain entered the company May 9, 1966.

He received the latest training of Emergency Procedures on Feb. 24, 1991.

(2) Copilot: Male, Aged 52

Airline Transport Pilot License	acquired July 1978
Type Rating Boeing 747-400	acquired on Sept. 9, 1989
	(latest revision August 20, 1991)
Class 1 Medical Certificate	
	issued July 17, 1991 (valid until July 31,1992)
Total Flight Experience	17,797 hours
Flight Experience on the type	965 hours
Flight Time in last 90 days	178 hours 18 minutes
Flight Time in last 30 days	32 hours 00 minutes
Rest period before the flight	21 hours 13 minutes

Note: The copilot entered the company January 6, 1969.

He received the latest training of Emergency Procedures on Feb. 7, 1991.

(3) Alternate Captain : Male, Aged 54

Airline Transport Pilot License	acquired June 1979
Type Rating Boeing 747-400	acquired on Feb. 20, 1991
	(latest revision August 31, 1991)
Class 1 Medical Certificate	
	issued April 9, 1991 (valid until Oct.31, 1991)
Total Flight Experience	15,457 hours

Flight Experience on the type	413 hours 13 minutes
Flight Time in last 90 days	249 hours 27 minutes
Flight Time in last 30 days	60 hours 03 minutes
Rest period before the flight	49 hours 15 minutes

Note: He entered the company May 23, 1966.

He received the latest training of Emergency Procedures on Feb. 22, 1991.

(4) Alternate Copilot : Male, Aged 39

Airline Transport Pilot License	acquired Feb. 1976
Type Rating Boeing 747-400	acquired on Sept. 19, 1990 (latest revision June 16, 1991)
Class 1 Medical Certificate	issued May 6, 1991 (valid until May.31, 1992)
Total Flight Experience	5,520 hours
Flight Experience on the type	600 hours
Flight Time in last 90 days	206 hours 44 minutes
Flight Time in last 30 days	31 hours 54 minutes
Rest period before the flight	49 hours 15 minutes

Note: He entered the company Oct. 10, 1983.

He received the latest training of Emergency Procedures on Feb. 12, 1991.

2.5.2 Cabin Crew

(1) Lead Flight Attendant A Female, Aged 40

Position during evacuation	Door L1
acquired qualification as attendant	April 22, 1974
Latest training on emergency procedures	June 1991
Rest period before the flight	more than 24 hours

(2) Flight Attendant B Female, Aged 37

Position during evacuation	Door L2
acquired qualification as attendant	June 24, 1974
Latest training on emergency procedures	Sept. 1991
Rest period before the flight	more than 24 hours

(3) Flight Attendant C Female, Aged 41

Position during evacuation	Door L2, assistant
acquired qualification as attendant	Feb. 26, 1973
Latest training on emergency procedures	July 1991
Rest period before the flight	more than 24 hours

(4) Flight Attendant D Female, Aged 37

Position during evacuation	Door L3
acquired qualification as attendant	Feb. 6, 1978
Latest training on emergency procedures	August 1991
Rest period before the flight	more than 24 hours

(5) Flight Attendant E Female, Aged 33

Position during evacuation	Door L3, assistant
acquired qualification as attendant	Feb. 5, 1979
Latest training on emergency procedures	August 1991
Rest period before the flight	more than 24 hours

(6) Flight Attendant F Female, Aged 34

Position during evacuation	Door L4
acquired qualification as attendant	May 11, 1977
Latest training on emergency procedures	April 1991
Rest period before the flight	more than 24 hours

(7) Flight Attendant G Female, Aged 39

Position during evacuation	Door L4 assistant
acquired qualification as attendant	June 24, 1974
Latest training on emergency procedures	May 1991
Rest period before the flight	more than 24 hours

(8) Flight Attendant H Female, Aged 26

Position during evacuation	Door L5
acquired qualification as attendant	August 4, 1990
Latest training on emergency procedures	August 1991
Rest period before the flight	more than 24 hours

(9) Flight Attendant I Female, Aged 37

Position during evacuation	Door R1

acquired qualification as attendant	January 31, 1977
Latest training on emergency procedures	March 1991
Rest period before the flight	more than 24 hours

(10) Flight Attendant J Female, Aged 32

Position during evacuation	Door R1, assistant
acquired qualification as attendant	January 15, 1979
Latest training on emergency procedures	August 1991
Rest period before the flight	more than 24 hours

(11) Flight Attendant K Female, Aged 29

Position during evacuation	Door R2
acquired qualification as attendant	April 30, 1984
Latest training on emergency procedures	May 1991
Rest period before the flight	more than 24 hours

(12) Flight Attendant L Female, Aged 38

Position during evacuation	Door R2, assistant
acquired qualification as attendant	January 17, 1977
Latest training on emergency procedures	March 1991
Rest period before the flight	more than 24 hours

(13) Flight Attendant M Female, Aged 36

Position during evacuation	Door R3
acquired qualification as attendant	June 11, 1979
Latest training on emergency procedures	April 1991
Rest period before the flight	more than 24 hours

(14) Flight Attendant N Female, Aged 28

Position during evacuation	Door R4
acquired qualification as attendant	January 24, 1990
Latest training on emergency procedures	May 1991
Rest period before the flight	more than 24 hours

(15) Flight Attendant O Female, Aged 45

Position during evacuation	Door R5
acquired qualification as attendant	April 7, 1990

Latest training on emergency procedures May 1991

Rest period before the flight more than 24 hours

(16) On-Board Service Manager P Female, Aged 24

acquired qualification as attendant June 18, 1990

Latest training on emergency procedures Feb. 1991

Rest period before the flight more than 24 hours

(17) Interpreter Q Female, Aged 24

acquired qualification as attendant March 16, 1987

Latest training on emergency procedures Feb. 1991

Rest period before the flight more than 24 hours

2.6 Aircraft Information

2.6.1 Aircraft

Type:	Boeing 747-400
Serial Number:	23818 (Line No. 715)
Date of Manufacture:	January 1989
Certificate of Airworthiness:	issued January 15, 1989
Total Time:	9,474 hours 43 minutes
Time since Previous Inspection (Inspection A conducted August 31, 1991):	270 hours 58 minutes

2.6.2 Engines

Type: Pratt and Whitney PW-4056

Serial No.	No.1 17518	No.2 17580	No.3 17566	No.4 17519
Date of Manufacture	July 5,1988	March 31,1989	Feb. 7,1989	July 3, 1988
Total Run Hours	9,474 h 43'	4,743 h 20'	6,904 h 17'	9,474 h 43'
Run Hours				

since previous inspection	270 h 58'	270 h 58'	270 h 58'	270 h 58'

2.6.3 Weight and Center of Gravity

The weight of the aircraft at the time of landing is calculated as approximately 626,000 pounds and the center of gravity as 25.0 % MAC, and both being within allowable limits (the maximum landing weight is 630,000 pounds, and the center of gravity corresponding to the weight at the time of landing is 13.0 ~ 33.0 % MAC).

2.6.4 Fuel and Lubrication Oil

The fuel on board was JET A-1 and lubrication oil was Esso 2380 (MIL-L-23699), both being regular products for the aircraft use.

2.7 Meteorological Information

2.7.1 Synoptic Weather

The synoptic weather disclosed by Choshi District Weather Service Center of the Meteorological Agency at 0900 UTC of the day was as follows:

> Typhoon 18 is proceeding to NE direction over ocean SSW of the Hachijo Island, and an autumn rain front is becoming active. Caution should be exercised since both the wind and rain are expected to remain strong in Chiba Prefecture until the midnight.
> Presently, the following warnings and advisories have been issued:
>
> > warning for heavy rain and flood, and advisory for thunderstorm, gale and high waves, to NW area of Chiba Prefecture; warning for heavy rain, flood, storm and high waves, and advisory for thunderstorm to NE area of Chiba Prefecture; and warning for heavy rain, flood, storm and high waves, and advisory for thunderstorm to S area of Chiba Prefecture.

2.7.2 Surface Chart

In Attached Figs. 3 a) and b) are shown the Surface Charts (a part of ASAS: the Asia Surface Analysis) at 0600 UTC and 1200 UTC of the day disclosed by the Meteorological Agency.

2.7.3 Upper-Air Chart

In Attached Figs. 4 a) ~ d) are shown 850, 700, 500 and 300 hPa Upper-Air Charts at 0000 UTC and 1200 UTC of the day disclosed by the Meteorological Agency.

2.7.4 Aeronautical Meteorological Observations at Narita Airport

The following are routine and special aeronautical meteorological observations by the Aviation Weather Service Center, New Tokyo International Airport in the time zones relating to the accident.

0900 UTC	Wind direction/speed	040 deg/05 kt
	Visibility, Weather	2,500 meters, heavy showers(81)
	Cloud	3/8 ST 500 ft 7/8 CU 2,000 ft
	Tem/Dew Pt.	22° C/22° C
	QNH	29.19 inches Hg
	Remarks	Haze, temporally 5/8 ST 500 ft 7/8 CU 2,000 ft
0919 UTC	Wind direction/speed	060 deg/05 kt
	Visibility, Weather	2,500 meters, heavy showers(81)
	Cloud	5/8 ST 200 ft 7/8 CU 1,500 ft
	Remarks	Haze
0930 UTC	Wind direction/speed	variable/05 kt
	Visibility, Weather	3,200 meters, heavy showers(81)
	Cloud	3/8 ST 200 ft 7/8 CU 1,500 ft
	Tem/Dew Pt.	22° C/22° C
	QNH	29.18 inches Hg
	Remarks	Haze, temporally 040 deg/25 kt max. 40 kt, 5/8 ST 500 ft 7/8 CU 1,500 ft

0937 UTC	Wind direction/speed	240 deg/06 kt
	Visibility, Weather	3,000 meters, heavy showers(81)
	Cloud	5/8 ST 200 ft 7/8 CU 1,500 ft
	Remarks	Haze
1000 UTC	Wind direction/speed	050 deg/09 kt
	Visibility, Weather	2,800 meters, heavy showers(81)
	Cloud	5/8 ST 200 ft 7/8 CU 1,400 ft
	Tem/Dew Pt.	22° C/22° C
	QNH	29.18 inches Hg
	Remarks	Haze, temporally 040 deg/25 kt max.40 kt, 5/8 ST 500 ft 7/8 CU 1,500 ft
1020 UTC	Wind direction/speed	020 deg/07 kt
	Visibility, Weather	2,200 meters, heavy showers(81)
	Cloud	6/8 ST 200 ft 7/8 CU 1,200 ft
	Remarks	Haze
1030 UTC	Wind direction/speed	020 deg/07 kt
	Visibility, Weather	2,200 meters, heavy showers(81)
	Cloud	6/8 ST 200 ft 7/8 CU 1,200 ft
	Tem/Dew Pt.	22° C/22° C
	QNH	29.19 inches Hg
	Remarks	Haze, temporally 040 deg/25 kt max.40 kt, 5/8 ST 500 ft 7/8 CU 1,500 ft
1100 UTC	Wind direction/speed	350 deg/07 kt
	Visibility, Weather	2,200 meters, heavy showers(81)
	Cloud	5/8 ST 200 ft 7/8 CU 1,200 ft
	Tem/Dew Pt.	22° C/22° C
	QNH	29.19 inches Hg
	Remarks	Haze, temporally 040 deg/25 kt max.40 kt, 5/8 ST 500 ft 7/8 CU 1,500 ft

(Note) The figure (81) in the weather above indicates a moderate or heavy shower of which momentous intensity at the time of observation is 3.0 mm/hour～25.0 mm/hour.

Amounts of precipitation per hour observed by Aviation Weather Service Center, New Tokyo International Airport in the time zone relating to the accident are as follows:

0900 UTC	20.5 mm
1000 UTC	11.0 mm
1100 UTC	5.0 mm

2.7.5 Meteorological Conditions in flight

According to the flight crew, meteorological conditions in flight were as follows:

Takeoff and landing were made in a shower, and below the flight level 240 flight was made mostly within clouds except that the aircraft was occasionally out of clouds when dumping fuel at an altitude of 10,000 ft. Light to moderate turbulences were encountered during climb near Choshi after takeoff, as well as during approach on ILS to Narita Airport.

2.8 Communications

The aircraft had maintained communication with Tokyo Area Control Center(on 133.6 MHz), Narita Approach Control (on 125.8 MHz and 120.2 MHz) and Narita Tower (on 118.2 MHz) after abnormalities occurred to the aircraft and the aircraft initiated return to Narita Airport. Communications with these facilities had been kept good.

2.9 Aids to Navigation and others

2.9.1 Aerodrome

Narita Airport is in Narita City of Chiba Prefecture located about 60 km east of the center of Tokyo and the airport is administered by New Tokyo International Airport Authority.

Elevation of the airport is 41 meters, and the runways 16/34, 4,000 meters in length, 60 meters in width paved with asphalt concrete and grooved 3,250 meters long and 60 meters wide.
Runway 34 was used for takeoff and landing of the aircraft and the runway had been in normal operation.

2.9.2 Aids to Navigation

Aerodrome facilities required for operation of the aircraft and aids to navigation related to the flight route of the aircraft were all in normal operation during the time zone related to the operation of the aircraft.

2.10 Flight Data Recorder and Cockpit Voice Recorder

The aircraft was equipped with a Fairchild Model F800 Digital Flight Data Recorder (hereinafter referred to as DFDR), and a Fairchild Model A100A Cockpit Voice Recorder (hereinafter referred to as CVR).
Both equipment, which were installed in the aft equipment center in the aft fuselage, were recovered intact.

2.10.1 DFDR

In DFDR were recorded all flight data from 0850:59 UTC at which an engine was started first to take off Narita Airport through to 1036:12 UTC at which all engines were shut down prior to execution of emergency evacuation of passengers and crew after the aircraft returned to the airport due to occurrence of abnormalities in flight. (The DFDR is capable of 25 hours recording, and recording begins when one engine starts and ends when all engines are shutdown.)

There was an unreadable part in DFDR record which was probably caused at time the record track was switched over, but the recording was in a good condition on

the whole.
Main results of analysis on DFDR record are shown in para. 3.1.2.

2.10.2 CVR

In CVR were recorded all data from 1005:22 UTC at which time fuel dumping was being conducted through to 1036:42 UTC at which time power to run CVR went off due to shut-down of all engines and the auxiliary power unit (APU) prior to emergency evacuation of passengers and crew after the aircraft returned to Narita Airport. The CVR is capable only of 30 minutes recording, and most of voice communications of the flight crew, after about 0921 UTC at which several messages indicating system malfunctions were shown on EICAS, did not remain in the record. The source of each channel of CVR was as follows:

Channel 1 : Audio Control Panel on Observer's seat
Channel 2 : Audio Control Panel on Co-pilot's seat
Channel 3 : Audio Control Panel on Captain's seat
Channel 4 : Area Microphone

However, it was difficult to separate voice communications exchanged between crew in the cockpit from ATC communications, and a part of the record was unanalizable, because the flight crew was monitoring the ATC communications by speakers in the cockpit, and they were mixed in into Channel 4.
CVR records in the emergency evacuation are shown in para. 3.1.3.

2.11 Medical Information

Out of a total of 315 persons on board consisting of a crew of 21 and 294 passengers, eight passengers were seriously injured. According to the diagnosis of the hospital where they were accommodated, six of the seriously injured sustained fracture of the thoracic vertebra, lumbar vertebra, or leg joint, while the other two sustained sprain. Besides, 38 persons were slightly injured, and their injuries were bruise, sprain, graze, etc., according to records of hospitals where they received treatment.
According to the injured persons, they suffered the injury in the emergency evacuation.

2.12 Information on search, rescue and evacuation relating to survival or death of, or injury to persons

2.12.1 Emergency training of crew

Company regulations of Northwest Airlines prescribe that flight crew and cabin attendants must receive training on emergency procedures once a year, and record of the company indicates that the crew had received the said training as described in para. 2.5.

2.12.2 Actions taken by flight crew in emergency evacuation

According to the flight crew, actions which were taken by them at the time the system malfunction occurred and the emergency landing and emergency evacuation were made are as follows:

During the period fuel dumping was being carried out for return, the flight crew informed cabin attendants that emergency landing on Narita Airport would be made because of system malfunctions, and cabin announcement to that effect was also made to passengers.

Since malfunctions relating to No.1 engine were displayed on EICAS, the flight crew judged the fire which actually occurred near No.2 engine in landing roll as a fire of No.1 engine, shut down No.1 engine, pulled the fire handle, stopped on the taxiway, and waited for tow, considering loss of No.1 hydraulic pressure.

Since a fire occurred again near No.2 engine, the captain shut down No.2 engine, and pulled the fire handle. At this time he decided to make an emergency evacuation and about 1035:40 UTC gave cabin attendants the instruction "EASY VICTOR" (an instruction for cabin attendants to be prepared for an emergency evacuation) and directed about 1035:50 UTC passengers through the Passenger Address System (PA) to make emergency evacuation from the right-side of the aircraft. This was followed by shut-down of other engines, discharge of extinguisher, and confirmation of the emergency procedures by the emergency evacuation check list.

Around this time, the captain was told by the alternate captain who went to the cabin to confirmed the situation there and returned that the cabin was not depressurized and doors on the main deck could not be opened. The captain then attempted to open manually the outflow valve. According to the captain, he was uncertain of whether there was power source available to control the valve after all engines had been shut down, and also of whether the valve could be opened since the valve had become uncontrollable before landing, but when he was holding the outflow valve manual control to open, he observed passengers who evacuated and running away from the aircraft through the right-side window, by which he became aware that doors had been opened.

The flight crew evacuated out of the aircraft after evacuation of all passengers was confirmed, and attended thereafter to guidance of passengers.

The captain stated that the auto-control of cabin pressurization became ineffective in flight necessitating a manual control and thereafter pointers of the instrument to indicate the position of the outflow valves became stuck and unmovable, but he had been counting that the cabin would be depressurized automatically at the time of touch-town; and also that the cabin altitude would have been approximately minus 400 ft at the time of landing.

2.12.3 Actions taken by cabin attendants in emergency evacuation

According to all cabin attendants and several passengers, actions which were taken by cabin attendants in reference to the emergency evacuation are as follows:

Lead Flight Attendant A, chief of cabin attendants, who went to the cockpit because she couldn't contact the cockpit through L1 interphone, was informed by the flight crew that an abnormal situation occurred, and then she notified all cabin attendants to that effect and direct them to remain seated until further noticed.

For a while thereafter rise in cabin temperature was felt. Lead Flight Attendant A who visited again the cockpit saw all members of the flight crew putting the oxygen mask on in a tense atmosphere, and was informed that the aircraft would return to Narita Airport for emergency landing and given instructions necessary therefor. She then notified all cabin attendants to that effect. Announcement to that effect was also made by the flight crew through the passenger address system. A and cabin attendants in charge made the announcement to passengers in English, Chinese and Japanese by the passenger address system, and at the same time passengers on the upper deck were removed to vacant seats on the main deck. A briefing was given to passengers of the emergency landing as well as emergency evacuation.

To prepare for the evacuation, the cabin attendant in charge of each door assigned from among passengers several able-bodied persons per each door whose assistance would be requested in the emergency evacuation as "ABP" and briefing was made to them on assisting procedures in emergency evacuation.

Touch-down was made smoothly, but, during landing roll, several cabin attendants and passengers observed a fire occurred near a left-side engine. This fire was extinguished soon, but when the aircraft came to a stop, a large fire flame was recognized at the same place, and some of passengers seated on the left side in the central part of the cabin who observed the flame rushed to the right side doors crying "Fire".
After the aircraft came to a stop on the taxiway, in accordance with the instruction of the flight crew to make an emergency evacuation from the right side, each cabin attendant in charge tried to open the door, but the handle of the doors were difficult to rotate, and with the help of "ABP" the doors were finally opened. About one minute was required for this, and some said that when the door was opened, a hissing sound like leaking air was heard. R1 door(the foremost on right side), R2 door (the second on right side), R4 door(the 4th on right side), and R5 door(the aftmost on right side) were opened, and their respective escape slide was deployed. R3 door (the middle on right side) was not used because outside of the window was seen glowing red. L1 door, the fore most on the left side was also opened, because of delay in opening right-side doors, at the discretion of A, and the escape slide was deployed, L2～L5 doors were not used.

2.12.4 Emergency Evacuation and Refuge

According to part of passengers, cabin attendants, and fire fighting personnel, the emergency evacuation was conducted and refuge was taken, after the doors were opened, as follows:

Since fire was observed from within the cabin, and time was required for opening doors, part of passengers became panic-stricken. Neighborhood of doors were congested with passengers.After doors were opened and escape slides deployed, passengers scrambled for evacuation to the taxiway in a shower and in the dark night except at R5 door which comparatively few people rushed to.

At the time of landing from escape slides, passengers collided with paved ground surface, or collided a preceding or following passengers, and thereby many of them received hard blow at back, buttocks, limbs, etc.

Most of passengers who evacuated took refuge by the guidance of the crew, but there were some who took refuge as far near to the runway, ignorant of the instruction by the crew. All passengers were finally guided by fire fighting personnel to a glassy area near crossing of Taxiway A and Taxiway A3 windward of the aircraft.

2.12.5 Fire fighting and rescue service at Narita Airport

(1) Outline of fire fighting and rescue service at Narita Airport

The fire fighting and rescue service is a service to be provided by New Tokyo International Airport Authority (hereinafter referred to as "Airport Authority"), and Airport Authority has concluded agreements on fire fighting and rescue activities with Narita City and neighboring local communities for their assistance made available any time upon request.

The Fire Fighting Section of Security Division of Airport Authority has Control Room , and Fire Fighting Station where fire fighting vehicles are waiting at the east side area of the airport, and a satellite where fire fighting vehicles are waiting near the middle on west side of the runway; and the fire fighting and rescue service is provided in shifts on a 24-hour basis.

The system involving equipment and personnel meets requirements prescribed in ICAO Annex 14 "Aerodrome" with respect to equipment, personnel, etc. At the time of the accident, 22 fire fighting personnel were on duty.

(2) Notification of information and request of services

Notification about occurrence of aircraft accident and request of the service would be made to Control Room of Fire Fighting Section of Airport Authority from Tower or Flight Operation of New Tokyo Airport Office, Operations Office of Airport Authority, airlines office, etc. The Control Room, upon reception of the notification or request, would issue directions to the fire station and its satellite using a microphone capable of simultaneous broadcasting. Furthermore, Control Room would request, when necessary, assistance of Fire Fighting Headquarters of Narita City and other related units.

2.12.6 Fire fighting and rescue activities

(1) Request of fire fighting and rescue service and dispatch of fire fighting and rescue vehicles

At 0942 UTC Control Room of Fire Fighting Section received from Tower that the aircraft was returning to the airport due to occurrence of an emergency situation. Upon its receipt, Control Room instructed the fire station and its satellite to prepare for Class 1 Order (the alert order); and also gave the information to Fire Fighting Headquarters of Narita City. Furthermore, upon receipt of the report at 1012 UTC that the aircraft was requesting arrangement of emergency vehicles, Control Room issued Class 2 Order (the emergency order) to the fire station and its satellite. The commanding car, one chemical fire fighting vehicle, one water tank truck, two ambulances, one medical equipment carrier truck and one crash rescue truck of the fire station were standing by on M1 Taxiway, while two chemical fire fighting vehicles and three water tank trucks of the satellite were standing by in front of the satellite station. All vehicles except the medical equipment carrier truck, together with two fire fighting vehicles of Sanrizuka Fire Station of Narita City Fire Fighting Department which arrived 1024 UTC, followed the aircraft which touched down 1031 UTC and was in landing roll. In addition, at 1058 UTC 3 fire fighting vehicles and 2 ambulances of Narita Fire Fighting Station of Narita City Fire Fighting Department, and at 1131 UTC an ambulance of Akasaka Fire Fighting Station and at 1227 UTC an ambulance of Sanrizuka Fire Fighting Station of Narita City Fire Fighting Department arrived at the airport.

(2) Fire fighting and rescue activities

According to Fire Fighting Section and Fire Fighting Headquarters of Narita City, the fire fighting and rescue activities by fire fighting personnel at the accident site were as follows:

The aircraft landed at 1031 UTC. The commanding car, which followed the aircraft in landing roll, recognized that a fire occurred about 1032 UTC in the vicinity of No.2 engine. The fire was soon put out. However, fire was again recognized at the same place soon after the aircraft came to a stop on Taxiway A near the crossing with Taxiway P1. Therefore, three fire fighting vehicles immediately discharged foam extinguisher. The fire was put out about 1036 UTC, but the discharge of extinguisher was continued until 1045 UTC to prevent recurrence of fire. About 1036 UTC when the fire was put out, escape slides were deployed, evacuation was begun, and evacuation of all passengers was finished about 1040 UTC.

Thereafter all passengers including some who were taking refuge towards the runway were guided to a grassy area near the crossing of Taxiway A and Taxiway A3, windward of the aircraft. About 1046 UTC transportation of the injured to a medical clinic within the airport was started by two ambulances and the commanding car. Passengers not injured were transported by six airport limousines to the terminal building, and transportation of all passengers finished at 1105 UTC. Since the injured was many as to be accommodated in the clinic alone within the airport, part of the injured passengers were transported to a hospital in Narita City by ambulances of Fire Fighting Section of Airport Authority and Fire Fighting Department of Narita City. The transportation began 1106 UTC and finished 1407 UTC, being made on a upon request of the injured basis. A total of 26 injured passengers were thus transported.

About 1301 UTC while the aircraft was parking at Spot 313 after it was tugged from the taxiway, the fire occurred for the third time near No.2 engine. The fire was extinguished by discharge of foam extinguisher of a chemical fire fighting vehicle which was standing by on alert. A mechanic of Northwest Airlines joined in the operation using a fire extinguisher for ground support. At 1320 UTC it was confirmed that there was no further possibility of fire and the stand-by on alert was released at 1328 UTC.

2.13 Tests and Research

2.13.1 Conditions of Aircraft after Accident

(1) Flaps

Three panels of the inboard group (No. 14 ~ No. 16) and 2 panels of the midspan group (No. 17 ~ No. 18) of right wing leading edge flaps drooped to some extent. The rest of right wing leading edge flaps and all left wing leading edge flaps were retracted.

The trailing edge flaps were in 20 units down position.

(2) Outflow valves

As to position of outflow valves, the left was "full open", and the right was "full close".

(3) The position of main levers, switches and circuit breakers within the cockpit were as follows:

* Engine

Fuel control switches	cut off (all engines)
Electrical engine control mode switches	normal (all engines)
Fire handles	pull out(all engines) rotate (right)

* APU

APU control switch	off
Fire handle	in

* Electrical system

Bus tie switches	all: auto
Generator control switches	all: on
Battery switch	off
Emergency light switch	on

* Flaps

Flap lever	20 units

* Fuel system

Fuel pumps

Main tank pump (booster pump) switches

Main 1 tank	fore and aft: on
Main 2 tank	fore and aft: on
Center tank	left and right: on
Main 3 tank	fore and aft: on
Main 4 tank	fore: off aft: on
Stabilizer tank	left and right: off

Override/fuel jettison pump switches

Main 2 tank	fore and aft: off
Main 3 tank	fore and aft: off

Fuel jettison control selector	off
Fuel jettison nozzle switches	left: on right: off

* Cabin pressurization system

Landing altitude selector	auto
Outflow valve manual switches	left: on right: off
Cabin altitude auto-selector	normal

* Air-conditioning system

Pack control selectors	pack 1: off pack 2, 3: normal
Cabin temperature selector	9 O'clock position
Cockpit temperature selector	9 O'clock position
Trim air switch	on

* Pneumatic system

Isolation valve switches	left: close right: open
Engine bleed air switches	1, 2: off 3, 4: on

* Anti-ice system

nacelle anti-ice switches	all: off
wing anti-ice switch	off

* For circuit breakers, part of hydraulic systems were only found popped out.

2.13.2 No.2 Engine Fuel Feed Pipe

No.2 engine fuel feed pipe is jointed to the front spar web of the wing at a location near ILES680 within the wing leading edge and installed in such a manner that it is bent down along the web, extends forward along the structure of the upper portion of the engine pylon strut, then goes into the engine strut to supply fuel to No.2 engine. On the other hand, No.1 generator feeder cable is disposed so that it crosses almost horizontally immediate front of the fuel feed pipe approximately 12 cm below the location where the fuel feed pipe is jointed to the spar web.

The diameter of the fuel feed pipe is approximately 2 inches (approximately 5 cm), thickness 0.035 inch (approximately 0.9 mm), and material an aluminum alloy (AA Spec. 6061-T4). Anticorrosive processing has been made on its outer surface.

On the fuel feed pipe of the aircraft at a location aft of the generator feeder cable crossing, there was found a hole of 8.2 mm in long diameter and 5.4 mm in short diameter. And the portion in defect (hole area x pipe thickness) of the pipe was approximately 28 mm3. The anticorrosive coating in the peripheral of the hole was chafed off with such traces remaining. The chafed portion was 9.9 mm in long diameter and 7.1 mm in short diameter. On the identification tape (material:glass fibre) pasted on the location of the fuel feed pipe where the hole was created, there was found a hole too of almost the same size as the hole on the pipe.

(see Attached Fig. 6, and Attached Photos. 1, 3, and 4)

2.13.3 No.1 Generator Feeder Cable

The generator feeder cable was manufactured in accordance with Material Spec. BMS13-35E(MIL Spec W-7072) of Boeing Company, the diameter of the cable is approximately 12.15 mm (approximately 0.48 inch), the conductor is twisted wires of an aluminum alloy, and insulation coating is three-plied polyimide tape coated with fluorocarbon {approximately 0.008 inch (approximately 0.2 mm) thick}. Rating of the generator is three-phase AC, 115/200 V, 400 Hz, and 90 KVA. The generator feeder cables in a bundle of three is passing through within the wing leading edge, and installed through clamps fore of the wing front spar. Inspection of the accident aircraft revealed that No. 1 generator feeder cable of the aircraft was damaged at a location (ILES680) in immediate front of the location where the location of the hole which was created on No. 2 engine fuel feed pipe. The damage was caused on one cable, out of three cables, the nearest to No.2 engine fuel feed pipe, and the insulation coating was damaged with a trace of an elliptic shape caused by rubbing abrasion where lamination of the polyimide tape was evidently seen and there was found a cavity on the conductor of aluminum alloy. The damage would have been caused by contact with No. 2 engine fuel feed pipe. The cavity on the conductor would have been caused by melting and had the evidence of electric discharge.

Size of the opening of the cavity in No.1 generator feeder cable is 7.9 mm in long diameter and 2.6 mm in short diameter and the abraded area of the insulation coating was 13.3 mm in long diameter and 6.9 mm in short diameter. The cavity caused by melting of the conductor was about 136 mm3 in volume. (see Attached Fig. 6 and Photos. 1, 5 and 6)

2.13.4 Clearance between Fuel Feed pipe and Generator Feeder Cable

The clearance between No.2 engine fuel feed pipe and No.1 Generator feeder cable within the left wing leading edge was approximately 6 mm. Specifications (No.D6-13053 Rev. L) of Boeing Company prescribe that the clearance between the fuel feed pipe and the generator feeder cable be at least 2 inches (approximately 50.8 mm), and that this minimum may be reduced only with engineering approval, in which case positive support or mechanical protection must be provided to prevent actual contact.

Meanwhile, clearance between No.3 engine fuel feed pipe and No.4 generator feeder cable within the right wing leading edge on the opposite side was 8 mm, but there was found no trace of contact there. Moreover, a spacer approximately 15 mm in length was used for the inboard clamp out of clamps located near ILES680 to fix the cable in order to ensure clearance from No.3 engine fuel feed pipe. However, no such spacer was used for the inboard clamp near ILES680 of the No.1 generator feeder cable.

2.13.5 No.2 Engine Fuel Feed Pipe Clamp

No.2 engine fuel feed pipe is fixed to structure of the upper portion of the pylon strut by a clamp just before it enters No.2 engine pylon. The clamp is composed of caps (of an aluminum), spacers (of an aluminum), bolts (of a steel), blocks (rubber), etc. (see Attached Figs. 6 and 7.) The outside bolt head of the clamp was fractured. Results of inspection on parts of the clamp made visually as well as by a scanning electron microscope (SEM) and others were as follows:

(1) Visual inspection

* Bolt 1

It was fractured at its head, and at the center of the fractured surface there was a rhombus-shaped plane of approximately 1.5 mm x 1.5 mm and surrounded by a rough surface. The diameter of the grip of the bolt (NAS1801-3-52) was within the specification.

* Bolt 2

No damage was recognized except that the plating of the grip was expanded by heat.

* Others

Some of washers were dented.

No damage was recognized on caps, spacers and self-lock nuts.

Block were burned.

(2) Investigation by SEM and X-ray Micro-analyser

The overall fractured surface was covered with cadmium, about 1/3 of which was spherical. The spherical cadmium was concentrated in the perimeter of the rhombus-shaped plane located in the center. The rhombus-shaped plane in the center was comparatively smooth.

2.13.6 Wire Bundles installed in the area fire occurred

In the area where fire occurred (ILES630~693) were installed, besides the generator feeder cable, 18 systems of wire bundles including engine control, instruments, wing leading edge flaps, fuel systems, pneumatic systems, anti-ice systems, engine overheat sensors, engine thrust reverser sensors.

Ten systems of wire bundles, out of the wire bundles in the said area, were significantly burned, and within some bundles short-circuit was found among wiring.

2.14 Other necessary information

2.14.1 Operating Limitation concerning cabin pressurization

In the company's Cockpit Operating Manual of Boeing 747-400, it is prescribed as an operating limitation of the aircraft that the maximum difference between the cabin pressure and the outer atmospheric pressure at takeoff or landing be 0.11 psi.

2.14.2 Operating procedures of outflow valves of cabin pressurization system

As to operating procedures of the outflow valves of the cabin pressurization system, the Cockpit Operating Manual describes under the item of emergency/abnormal procedures as follows:

(1) Operating procedures in case auto-control of cabin altitude failed

In case the auto-control of cabin altitude became inoperative and the caution message 《CABIN ALT AUTO》 was displayed on EICAS, cabin altitude should be manually controlled. Operating procedures in this case are as follows:

1. Place manual left and manual right outflow valve switches on

2. Place one pack control selector off

3. Position outflow valves manual switch open or close to maintain desired cabin altitude and cabin rate of approximately 500 ft/min for climb or descent.

4. Recommended cabin altitude in cruise is as shown below:

Cruising Altitude (flight level)	Recommended Cabin Altitude (ft)
up to 230	elevation of landing airport
260	2,000
300	4,000
350	6,000
400 & above	8.000

5. Preparation for landing : position both outflow valves to full open at the landing pattern altitude

(2) Procedures in emergency evacuation

In the emergency evacuation check list, it is prescribed to "check both outflow valves being open" after the parking brake was set and notification was made to the tower that an emergency evacuation is to be conducted.

2.14.3 Service Letter and Service Bulletin of Boeing Co.

The Boeing Company issued the following Service Letter and Service Bulletin although they are not directly relevant to this accident:

(1) Service Letter No.747-SL-24-17-A (as of July 27, 1990)

This Service Letter, applicable to Boeing 747-400 airplanes, recommends to prevent the clamps from being flexed or fractured by reinstalling the clamp in a "lobed down",instead of "lobed up", position through a support plate, taking into consideration instances reported in which the generator feeder cable clamps were fractured between the inboard engine and the outboard engine, and thereby the feeder cable and structural parts contacted each other, causing abrasion of insulation coating of the feeder cable, and leading to arcing as well as trip-off of the generator.

The accident aircraft was subjected to such modification as described in this Service Letter of the left and the right wing on January 25, 1991.

(2) Service Bulletin No.747-24-2170 (as of Dec.18, 1991)

This service bulletin is an SB version of the Service Letter above, and of almost the same contents as the Service Letter.

2.14.4 Repairs history of No.1 Generator Feeder Cable

In a flight of this aircraft on Oct. 8, 1990, approximately one year before this accident, EICAS messages of No.1 generator trip 《ELEC GEN OFF 1》 and No.1 generator failure 《ELEC GEN SYS 1》 were displayed. Inspection disclosed that No. 1 generator feeder cable was burned in the vicinity of the fuel supply panel located between No.1 engine and No.2 engine. The cause was that 2 clamps supporting the generator cable were fractured, thereby the feeder cable touched structural parts, and the insulation coating was damaged leading to arcing.

Repairs to splice the cable was conducted and clamps were changed for the aircraft on that day.

3 Analysis

3.1 Tests and Research for Analysis

3.1.1 Record of Central Maintenance Computer (CMC)

(1) Central maintenance computer

Boeing 747-400 airplanes have a central maintenance computer (CMC) on board. Messages displayed on EICAS and fault messages on components which caused the display of the messages are recorded in CMC. By reading out the EICAS messages and fault messages recorded in CMC, status of system malfunctions during operation could be reproduced for reference prior to maintenance work.

In the Aircraft Operating Manual and the Minimum Equipment List (MEL) of Boeing 747-400 of Northwest Airlines, each message is described as follows:

> EICAS messages are divided into three categories: status, memo and alert.
>
> Status messages indicate faults which may affect dispatch capability of the aircraft.

Memo messages are to call attention to the normal aircraft configuration or systems status and not to indicate any fault.

Alert message are divided into three levels: warning, caution and advisory, and appear on the primary EICAS display.

The meaning of each message is as follows:

(1) The warning message is the highest priority alert message, displayed in red at the top of the message list. It is accompanied by the red master warning light and aural alert (bell, siren, or voice). Immediate crew action is required.

(2) The caution message is the alert message of the second highest priority next to the warning message, displayed in amber below the warning level messages. It is accompanied by amber master caution light and aural alert (beeper or voice). Immediate crew awareness and future crew action is required.

(3) The advisory message is the lowest alert message, displayed in amber below any caution level messages and indented one space to the right. Crew awareness and possible future crew action are required.

(4) The memo message is reminders of current state of certain normal conditions for crew awareness only, and displayed in white on the primary EICAS display.

(5) The status message is a white message displayed on the secondary EICAS to indicate system conditions which may affect dispatch. In case the status display is not selected, a status cue is shown on the primary EICAS display indicating that there is a new status message. It is only necessary to report the status message which would be displayed after takeoff, because the message which requires crew action is displayed as an alert message.

The alert message and the status message displayed prior to dispatch affect aircraft dispatchability. Either conditions causing these messages should be corrected, or the dispatchability should be determined based on the Minimum Equipment List (MEL).

The maintenance message is generated by CMC, and do not appear on EICAS. This message provides information regarding system faults and correlation with indications in the cockpit, and is displayed on the CMC control display unit in the cockpit.

Note: According to FAA's Type Certificate Data Sheet (No. A20WE) of Boeing 747-400, each message is defined as follow:

(1) The warning message indicates conditions of aircraft operation or systems which require immediate awareness and immediate corrective or compensatory action by the crew.

(2) The caution message indicates conditions of aircraft operation or systems which require immediate awareness and prompt compensatory action by the crew.

(3) The advisory message indicates conditions of aircraft operation or systems which require timely awareness of crew as needed for future compensatory action.

(4) The memo message is to remind the crew of the current state of selected normal conditions, not necessarily requiring crew awareness for action unless specified in procedures.

(5) The status message indicates aircraft's condition necessary for ground crew and flight crew to determine its dispatch capability.

(6) The CMC message indicates a detailed maintenance-related message necessary for the ground crew to comprehend airplane faults in maintenance work.

(2) CMC record

In the CMC were recorded data of malfunctions which occurred in each system during the period from the time abnormality occurred in flight to the time the aircraft returned to the airport and power source was cut off prior to the emergency evacuation. Malfunction data on preceding 13 legs of flight was also recorded. The data of this flight which was read out indicated that 6 caution messages, 13 advisory messages and 23 status messages were displayed; 42 EICAS messages in total. No warning message was recorded since no malfunction causing such display occurred.

Caution messages, advisory messages and status messages which were recorded in CMC are shown in the attached tables in the chronological order in which they were displayed on EICAS. Time displayed, discription, and fault indication are as shown in the following Tables 1 ~ 3.

"Time Occurred" represents the time occurrence of the said malfunction was first recorded. "HARD" in the column "Fault Indication" indicates that the said malfunction had continued until the engine stop phase was initiated, while "INT" indicates that the said malfunction had temporarily returned normal before the engine stop phase was initiated.

It is noted that the engine stop phase is initiated when the parking brake was set up on the ground and the last fuel control switch was brought in the cut-off position.

Table 1 Caution Messages which were recorded in CMC

EICAS Messages	Time (UTC)	Description	Fault Indication
BLD DUCT LEAK L	0921	Leak or overheat in left wing bleed air duct.	HARD
FLAPS PRIMARY	0921	One or more flap groups are	HARD

		operating in the secondary control mode.	
OVHT ENG 1 NAC	0921	Overheat condition detected in No.1 engine nacelle.	I N T
FLAPS DRIVE	0921	One or more flap groups have failed to drive in the secondary control mode, or an asymmetry condition is detected.	H A R D
>AUTOTHROT DISC	0923	Autothrottle had disengaged.	I N T
>AUTOPILOT	0923	Selected autopilot is operating in a degraded mode. The engaged roll and/or pitch mode may have failed.	I N T

Table 2 Advisory Messages which were recorded in CMC

EICAS Messages	Time (UTC)	Description	Fault Indication
ELEC DRIVE 1	0921	Low No.1 IDG oil prssure, or high No.1 IDG oil temperature when No.1 engine is run	I N T
ENG 1 FUEL VLV	0921	No.1 engine fuel valve or fuel spar valve position disagrees with commanded position.	H A R D
>FUEL JETT B	0921	Jettison system B has failed.	H A R D
ELEC GEN OFF 1	0921	No.1 generator control breaker is open when No.1 engine is run.	H A R D

>JETT NOZZLE L	0921	Left nozzle valve position disagree with commanded position.	HARD
NAI VALVE 1	0921	No.1 nacelle anti-ice valve is not in commanded position when No.1 engine is run	INT
FUEL X FEED 1	0922	No.1 crossfeed valve is not in commanded position.	HARD
>FMC MESSAGE	0923	High priority FMC message exist.	INT
ENG 1 EEC MODE	1031	No.1 engine EEC is in alternate control mode.	
>NO LAND 3	1032	Autoland system is no longer fail operational.	HARD
>BTL LO L ENG B	1032	Fire extinguisher bottle pressure is low.	HARD
ENG 2 FUEL VLV	1034	No.2 engine fuel valve or fuel spar valve position disagree with commanded position.	HARD
>BTL LO L ENG A	1035	Fire extinguisher bottle pressure is low.	HARD

Table 3 Status Messages which were recorded in CMC

EICAS Messages	Time (UTC)	Description	Fault Indication
FUEL SPAR VLV 1	0921	No.1 engine fuel spar valve position disagree with commanded position.	HARD

NAI DUCT 1 LEAK	0921	No.1 engine fan cowl temperature exceeds 250 ± 5° F.	INT
FLAP SYS MONITOR	0921	FCU or sensor fault which affects dispatch.	HARD
FUEL JETT B	0921	Jettison system B failure.	HARD
ELEC GEN SYS 1	0921	IDG 1 failed, generator feeder 1 failed, GCU 1 failed or is off, 28V backup to GCU 1 failed, ARINC bus from GCU 1 to BCU 1 or BCU 2 failed, or GCB 1 failed.	HARD
ENG 1 OVHT LP B	0921	Engine 1 nacelle overheat detector loop B overheat or fault output.	HARD
ENG 1 EEC C1	0921	Engine 1 EEC fault category 1 with time limited dispatch.	
ADC LEFT	0921	Left ADC failure.	HARD
ADC RIGHT	0921	Right ADC failure.	HARD
BLEED ASCTU A	0921	Channel A of air supply control and test unit failed or ARINC 429 bus invalid or missing.	HARD
FUEL QTY SYS	0921	Fuel quantity processor or input not operational.	HARD
JETT NOZZLE L	0921	Left jettison nozzle valve position disagree with commanded position.	HARD

Table 3 (continued)

EICAS Messages	Time (UTC)	Description	Fault Indication
LE MULT DRIVE	0921	Multiple leading edge failures	HARD
BLD DUCT LEAK L	0921	Left bleed duct leak or overheat.	HARD
ELEC DRIVE 1	0921	Low No.1 IDG oil pressure or high oil temperature when No.1 engine is run.	INT
ENG 1 OVHT LP A	0921	Engine 1 nacelle overheat detector loop A overheat or fault output.	HARD
ANTI-ICE NAC 1	0921	Engine 1 anti-ice valve disagree with commanded position with engine running or NAI valve pressure regurator failed.	INT
FUEL X FEED 1	0922	No.1 Tank fuel X feed valve disagree with commanded position.	HARD
ENG 1 EEC MODE	1031	Control is in alternate non-rating mode.	
GROUND PROX SYS	1031	Ground proximity system fault or input of false information to the system.	HARD
BTL LOW L ENG B	1032	Fire extinguisher bottle pressure is low.	HARD

FUEL SPAR VLV 2	1034	Engine 2 fuel spar valve disagree with commanded position.	H A R D
BTL LOW L ENG A	1035	Fire extinguisher bottle pressure is low.	H A R D

The flight crew stated that they remember, among other things, caution messages 〈OVHT ENG 1 NAC〉,〈BLEED DUCT LEAK L〉,〈FLAPS PRIMARY〉and 〈FLAPS DRIVE〉, and advisory messages 〈ELEC GEN OFF 1〉 and 〈JETT NOZZLE L〉 were displayed on EICAS. The display of these messages was, as stated above, confirmed by the CMC record. They further witnessed that, although their memory are not certain, other messages such as caution messages 〈CABIN ALT AUTO〉 and 〈STARTER CUTOUT〉, and advisory messages 〈BLEED 1 OVHT〉, 〈FMC L〉, 〈IDLE DISAGREE〉, 〈OUTFLOW VALVE L,R〉 and 〈WAI VALV L〉 were also displayed on EICAS. However, such messages were not recorded in CMC.

3.1.2 DFDR Record

In DFDR of the aircraft were recorded 114 items of flight data and 102 items of discrete signal (signals able to have 2 states such as "on", or "off")

Main records in DFDR were as follows: (see Attached Figs. 8 and 9)

(1) Time of DFDR

A comparative investigation made among ATC communication records, CVR records and timing of VHF transmitter's keying signal which was recorded in DFDR indicated a delay of approximately 17 seconds in the time recorded in DFDR. Therefore, times of DFDR are all corrected by adding 17 seconds.

(2) Summary of flight

According to flight data in DFDR, the aircraft took off Runway 34 of Narita Airport 0904:41 UTC, made a right turn, climbing nearly eastward, reached an altitude of approximately 27,000 ft at about 0922 UTC, and after a level flight for about 2 minutes, began to descend, and reached an altitude of approximately 10,000 ft at about 0931 UTC. After making a left turn the aircraft flew westward a level flight for approximately 48 minutes in which one circling clockwise was made, thereafter began further descent about 1019 UTC, and landed on Runway 34 of Narita Airport at 1031:12 UTC and came to a stop at 1033:55 UTC.

(3) Fuel dumping

Judging from change of fuel amount in record, the fuel on board decreased by approximately 167,000 pounds during a period from about 0931 UTC at which fuel dumping began to about 1023 UTC at which the dumping terminated.

The fuel remaining at the time of landing was approximately 136,000 pounds.

(4) Cabin pressure

The cabin pressure at the time of takeoff was 14.3 psia (absolute pressure in pound/square inch) in absolute pressure, decreased gradually with climb of the aircraft, to 13.1 psia at about 0921 UTC, thereafter from about 0923:30 UTC began to decrease drastically, and recorded a minimum of 9.6 psia (equivalent to a cabin altitude of approximately 11,300 ft when converted to the standard atmosphere. The same applies hereinafter.) about 0928 UTC. The ascent rate of the cabin altitude reached temporarily as much as approximately 1,700 ft/min, followed by approximately 1,100 ft/min. After about 0928 UTC the cabin pressure turned to increase, and continued to increase until reaching 16.8 psia (equivalent to a cabin altitude of minus 3,800 ft) at about 0943 UTC and the descent rate of cabin altitude reached approximately 1,500 ft/min, and temporarily 1,700 ft/min. During a period from 0943 UTC to the landing at 1031 UTC, the cabin pressure repeated a narrow range of variation nearly at 17 psia, and it was 17.0 psia (equivalent to a cabin altitude of approximately minus 4,000 ft) at the time the aircraft landed at 1031 UTC. A cabin pressure of 16.8 psia (equivalent to a cabin altitude of minus 3,800 ft) was recorded at about 1036 UTC when the emergency evacuation was directed. Actuation of the cabin altitude warning system was recorded for a period from 0926:46 UTC to 0929:31 UTC during which the cabin pressure decreased abnormally.

Note: The cabin altitude warning system is actuated when cabin altitude exceeds 10,000 ft.

(5) Actuation of stick shaker

Actuation of the stick shaker was recorded 5 times during a period from 0923:40 UTC to 0924:19 UTC. The CAS then were 255, 253 ~ 246, 245 ~ 246, 249 ~ 250, 257 ~ 258 knots, respectively. The aircraft weight was approximately 804,000 pounds,with flaps up and the flight altitude was 27,000 ~ 26,000 ft.

(6) Operation of cabin pressurization

The aircraft took off with only No. 1 air conditioning pack "on", and after 0907 UTC the aircraft was in climb with all three systems of air conditioning pack "on". Thereafter No.2 air conditioning pack and No.1 air conditioning pack were brought to "off" at 0922:10 and at 0923:37 UTC, respectively. No.2 air conditioning pack was brought again to "on" at 0942:10 UTC, but No.1 air conditioning pack remained "off" until the time DFDR recording terminated.

(7) Record on engine fire and engine overheat

There was no record of detected fire on this flight in DFDR. As to engine overheat, detection of No.1 engine overheat was recorded from 0922:05 UTC until the time the DFDR recording terminated.

(8) Operation of Engines

It was recorded that after takeoff each engine had been in normal operation until about 0922 UTC. Thereafter, according to RPM record of No.1 engine, the engine was in a nearly idling condition from about 0922 UTC until about 0930 UTC, but thereafter increased temporarily its output, and returned to idle again. From about 0934 UTC to about 0947 UTC it was used as a thrust in the same manner as other three engines, thereafter remained idle, and used again as a thrust to some extent before touch-down, and was shut down at 1032:14 UTC. There was no record that the thrust reverser of No.1 engine was used.

According to thrust reverser discrete signals, the reverser of No.1 engine had been in transit from 0921:36 UTC through to the time DFDR recording terminated.

Meanwhile, according to RPM record of No.2~ No.4 engines, they became idle temporarily about 0923 UTC when a nearly level flight was being made at an altitude of approximately 27,000 ft, then significant variation of thrust can be seen about two times, and again the idling condition continued up to about 0930 UTC, but thereafter they were in normal operation until touch-down. About 1031 UTC the thrust reverser of No.2 and No.3 engine were used. The thrust reverser of No.4 engine was also used as a thrust in an almost idling condition. Fuel flow became zero at 1034:27, 1036:11 UTC, and 1036:12 UTC, respectively, of No.2, No.3 and No.4 engine.

(9) Operation of Autothrottle

In this flight, the autothrottles were disconnected for approximately 11 minutes from 0924:01 UTC, for approximately 3 minutes from 0935:35 UTC, and for approximately 38 minutes from about 0940:46 UTC.

(10) Operation of Autopilot

Out of three systems (left, center and right) of autopilot, the center autopilot was engaged for approximately three minutes from 0922:32 UTC, approximately one minute from 0931:04, and approximately 53 minutes from 0938:10 UTC and up to immediately before touch-down. Both the left and the right autopilot were engaged for approximately 7 minutes from 1024:14 UTC up to immediately before touch-down.

(11) Operation of the wing anti-ice

The wing anti-ice had been "on" for a period from 0921:31 UTC which was immediately before the aircraft reached an altitude of approximately 27,000 ft until the time DFDR recording terminated.

3.1.3 Record of Emergency Evacuation in CVR

According CVR record, No.2 engine fire handle was pulled 1035:40 UTC, then "EASY VICTOR" was issued to cabin attendants to prepare for an emergency evacuation, and about 1035:50 UTC passengers were directed through the Passenger Address

System (PA) to make "emergency evacuation from the right side". This was followed by shut-down of other engines and read-out of the emergency procedures check list.

According to the flight crew, the operation to fully open the outflow valves, which is a set procedure at the landing pattern altitude during manual control of outflow valves, was conducted, but it could not be confirmed from CVR records. Moreover, although read-out by the copilot of "Check Outflow Valves Open" in the emergency evacuation check list was recorded, there was no voice recorded to have confirmed "open".

3.1.4 Melt of Generator Feeder cable and Fuel Feed Pipe

In the generator control unit (GCU) is incorporated a protective circuit to detect input speed of the integrated drive generator (IDG) (Rating: three-phase AC, 115/200 V, 400 Hz, and 90 KVA), cycle and voltage of IDG, and difference current between the output side of the generator and the bus side of AC power source, and to isolate abnormal power systems from normal power systems by one or combination of the following three methods in case the detected values deviated from their prescribed value:

(1) To stop generation of the related IDG, through actuation of the Generator Control Relay (GCR), by cutting off exciting current.

(2) To isolate the related IDG, through actuation of the Generator Circuit Breaker (GCB), from the AC power bus to which the power is supplied.

(3) To isolate the related AC power bus, through actuation of the Bus Tie Breaker (BTB), from other AC power buses.

When the insulation coating of No.1 generator feeder cable is damaged and the cable makes contact with No.2 engine fuel feed pipe, the generated output of No.1 IDG is shorted electrically.

If the difference current between the IDC side and the AC power side 20± 5 amperes for a period exceeding 20± 5 ms, the protective circuit of GCU actuates

GCR within 50 ms to stop generation by shutting off exciting current of No.1 IDG, and at the same time actuates GCB within 50 ms to isolate No.1 IDG from No.1 AC power bus (difference fault protective function). However, there was no record left in CMC that the difference fault protective function of the protective circuit was actuated.

When the rated input speed of No.1IDG decreased to less than 4,525± 125 rpm for a certain period (a maximum of 150± 50 ms), GCB of No.1 IDG is actuated and and No.1 AC power bus is isolated (under speed protective function). Activation of the protective function was recorded in a CMC fault message indicating fault of a component or wire which caused display of the advisory message 《ELEC GEN OFF 1》.

Arc current generated by the short-circuit is estimated to have been approximately 1,500 amperes, and if the arcing lasts for 20 ms, it would, theoretically, generate energy capable of melting aluminum alloy which constitutes materially the generator feeder cable and the fuel feed pipe by approximately 30 cubic mm, respectively, at both ends of the arc (portions where the arc touches the the generator feeder cable and the fuel feed pipe).

Furthermore, as stated in paras. 2.13.2 and 2.13.3, melt of the fuel feed pipe and the generator feeder cable are 28 cubic mm and 136 cubic mm, respectively, and it is conceivable that if an arcing of a duration shorter than the period the difference fault protection becomes functioned (20± 5 ms) occurred several times (approximately 100 ms in total) an energy capable of causing such melt could be generated. It is estimated that the melt was less for the fuel feed pipe than for the generator feeder cable, because thickness of the pipe is as thin as approximately 0.035 inch and fuel at low temperatures was constantly flowing in the pipe.

It is conceivable that an arcing could be triggered by a high voltage such as a lightning, but it is estimated that the melt of the generator feeder cable by arcing was not triggered by a lightning, because, as stated in para.2.13.3, around the damaged hole of the insulation coating of the cable, there remained a chafed trace of an elliptic shape where cumulated layers of the polyimide tape could evidently be seen and which should hardly be formed by such arcing.

From the above, details of melting of No.1 generator feeder cable and No.2 fuel feed pipe is estimated to have been as follows:

(1) The insulation coating was damaged by chafing between No.1 generator feeder cable and No.2 fuel feed pipe, and thereby both were electrically shorted.

(2) Arcing of a duration shorter than the period difference fault protective function became activated (20± 5 ms) was generated several times between No.1 generator feeder cable and No.2 fuel feed pipe.

(3) No.1 generator feeder cable and No.2 fuel feed pipe were melted by the arcing generated sevral times.

(4) Due to chafing as well as arcing resulting therefrom, a hole was opened on No.2 fuel feed pipe, from where fuel spouted, and the fuel was ignited by the arc to cause fire at the area.

(5) The wire to detect of input speed of No.1 IDG installed in the area where fire occurred was burned, the protective circuit judged that the input speed decreased, and the under speed protective function became activated to isolate No.1 IDG from No.1 AC power bus.

(6) It is considered that after GCB was actuated and the advisory message 《ELEC GEN OFF 1》 was displayed on EICAS, No.1 generator switch would have been reset ("OFF" then followed by "ON") in accordance with the procedure of the Cockpit Operating Manual. The EICAS message still remained on display, but procedures for such case were not set forth in the manual. For this reason, No.1 generator switch remained "ON" by the resetting operation, with the result that the control wire of No.1 IDG continued to function and No.1 IDG continued to generate power, and arcing of such a duration as not activate the difference fault protective function was generated repeatedly so that melt of No.1 generator feeder cable and No.2 feed pipe progressed.

3.1.5 Design standards on installation of Fuel Feed Pipe and Electric System Cable

(1) Out of FAA's design standards (Title 14, Chapter 1, Part 25 of Federal

Aviation Reguration: Airworthiness Standards of Transport Category Aircraft)(hereinafter referred to as "FAR") applicable to the aircraft, main design standards relating to installation of fuel feed pipes and electric system cables are as follows:

i) Fuel feed pipes

* FAR 25.993 (a) and (b)

(a) Each fuel line must be installed and supported to prevent excessive vibration and to withstand loads due to fuel pressure and accelerated flight conditions.

(b) Each fuel line connected to components of the airplane between which relative motion could exist must have provisions for flexibility.

ii) Electric system cables (electrical equipment and installations)

* FAR 25.1353 (a) and (b)

(a) Electrical equipment, controls, and wiring must be installed so that operation of any one unit or system of units will not adversely affect the simultaneous operation of any other electrical unit or system essential to the safe operation.

(b) Cables must be grouped, routed, and spaced so that damage to essential circuits will be minimized if there are faults in heavy current-carrying cables.

iii) Electric system cables (electrical system fire and smoke protection)

* FAR 25.863(a) and (b)

(a) In each area where flammable fluids or vapors by leakage of a fluid system, there must be means to minimize the probability of ignition of the fluids and vapors, and the resultant hazards if ignition does occur.

(b) Compliance with paragraph (a) of this section must be shown by analysis or tests, and the following factors must be considered:

1) (omitted)

2) (omitted)

3) Possible ignition sources, including electrical faults, overheating of equipment, and malfunctioning of protective devices.

*FAR 25.1359(c)

[Note] This standard should apply when installation is made within fuselage, and not when within wings.

(c) Main power cables (including generator cables) in the fuselage must be designed to allow a reasonable degree of deformation and stretching without failure and must

1) be isolated from flammable fluid lines; or

2) be shrouded by means of electrically insulated flexible conduit, or equivalent, which is in addition to the normal cable insulation.

iv) Equipment, systems and installations

* FAR 25.1309(a)

(a) The equipment, systems, and installations whose functioning is required by regulations, must be designed to ensure that they perform their intended functions under any foreseeable operating condition.

(2) In the current FAA advisory circular No. 25-16 "Electrical Fault and Fire Prevention and Protection" (dated April 5, 1991), which is a guide line on airworthiness standards of Transport Category Airplanes, a designing guide line is described for installation of the electric system as summarized below:

(a) To prevent insulation chafing, wires and bundles should be installed by routing and clamping to ensure sufficient spacing from structure or other parts after any single failure (for example, a single failure of a clamp or clamp fastener).

(b) Wires should not be routed between aircraft skin and fuel lines.

(c) It should be avoided to run wires along the bottom of the fuselage, over the landing gear, in areas of the leading edge of the wing where fuel spillage is anticipated, or adjacent to flammable fluid lines or tanks.

(d) Measures should be taken to avoid short-circuits and electric failure due to damage to the insulation coating of tanks, tubes or components containing fuel or other flammable fluid. For this purpose, consideration should be given to the maximum power which could be produced, and the physical or spatial separation provided between their possible locations and the areas of potential hazard.

(e) Physical or spatial separation should be provided between high-current cables and the areas of potential hazard by electrical failure. For locations where adequate separation is impractical such as the inside and vicinity of fuel tanks, and inside of nacelles or pylons, protection should be provided by an adequate barrier or conduit or by other acceptable means.

3.2 Analysis

3.2.1 Damage to No.1 generator feeder cable and No.2 engine fuel feed pipe

From the evidence of damage to the generator feeder cable and the fuel feed pipe touched it is estimated that they were chafed each other, thereby insulation coating of the cable was damaged and arcing was generated. As stated in para.2.13.4, on the fuel feed pipe there was damage considered as resulting from chafing and arcing, and on the generator feeder cable too, there was a cavity considered to have been caused by arcing.

As stated in para. 2.13.4, a measurement which was made after the accident indicated that the clearance between the generator feeder cable and the fuel feed pipe was 6 mm. It is unknown whether such clearance less than prescribed in Boeing Specifications (No.D6-13053 Rev.L) as stated in para. 2.13.4 was present from the time of production, or caused by the repair work of the feeder cable as stated in para.2.14.4. It is noted that the clearance at the corresponding location on the right-hand wing was 8 mm.

It is estimated that the narrow clearance between the generator feeder cable and the fuel feed pipe caused touching and chafing between them by bent of wings and vibration of the generator feeder cable. Contribution of vibration of the fuel feed pipe due to vibration of the airframe and the engine pylon would also be conceivable.

The head of the fuel feed pipe clamp bolt on the upper portion of No.2 engine pylon strut was fractured. It is considered that the fracture was caused by fire as stated in para. 3.2.3.

3.2.2 Details of occurrence of fire

The No.2 engine fuel feed pipe and No.1 generator feeder cable of the aircraft touched and chafed each other, thereby insulation coating was damaged and arcing was generated between the engine fuel feed pipe and the generator feeder cable. It is estimated that a hole was made in No.2 engine fuel feed pipe by the arcing possibly, being contributed also by chafing with the cable, and the fuel flowed out and was ignited by the arc to cause fire. It is also estimated that at this time the wire bundle installed within the left wing leading edge (ILES630～693) was burned, causing a short circuit or snapping, and thus messages on occurrence of various system malfunctions including the advisory message 《ELEC GEN OFF 1》 were displayed on EICAS. It is estimated that No.1 generator continued generation and the arcing was repeated because the generator remained "on" by resetting operation, although it was turned to "off" once.

It is recognized that the fire occurred only within the left wing leading edge(ILES630～693). It was confirmed that the blow-out panel located on the under surface of this portion and separable at a differential pressure of 2.5 psi was separated, but the panel could not be found within the boundaries of the airport. It is estimated that the blow-out panel was separated about 0921 UTC when the fire occurred in flight and the pressure within the left wing leading edge increased.
The altitude at the time the fire occurred is estimated to be approximately 26,000 ft, and CAS approximately 300 knots. However, it is recognized that the fire did not develop any further. The reason would be that the fire was blown out by air current coming in due to lack of the blow-out panel.

The aircraft landed at Narita Airport about 1031 UTC. It is recognized that fire occurred within the left wing leading edge about 1032 UTC during landing roll. It is estimated that the fire occurred because air current flowing in was becoming less with decrease in aircraft speed during the landing roll, and fuel which flowed out was ignited by spark or arc caused by short circuit of the generator feeder cable or the wire bundle damaged by fire in flight. It is estimated that by this fire the wire bundle installed in ILES 630～693 was damaged together with structural components in No.2 pylon upper strut, and that the extinguisher piping for left wing engines of an aluminum alloy was melted. The flight crew stated that they shut down No. 1 engine and pulled the fire handle, because they were advised from the tower "Left engine fired" and were thinking that No.1 engine was in malfunction. However, it is recognized that the extinguisher gas was given off to the fired area from the melted pipe, and the fire was once put off.

It is estimated, however, that fuel continued to flow out and sparking or arcing was being generated, and fire occurred again about 1035 UTC when the aircraft came to a stop on the taxiway. Fire fighting vehicles which were following the aircraft discharged extinguisher to the fired area. The flight crew state that they were informed by the tower that No.2 engine fired and confirmed it themselves, and shut down No.2 engine, and pulled the fire handle. It is recognized, however, that this time again extinguisher gas was discharged from the melted pipe to the fired area. It is estimated that as a result the fire was immediately extinguished.

The fire was once extinguished. The aircraft was towed to the parking area after the evacuation was completed. After a mechanic confirmed there was no leakage of fuel from the fuel feed pipe, and washed the said area, circuit breakers within the cockpit relating to No.1 and No.2 engine were pulled out. When an external power was connected to the aircraft about 1301 UTC in order to unload passengers' baggage, fuel flowed out through a hole on the fuel feed pipe and fire again occurred. It is estimated that it was caused because the booster pump switches of the left wing fuel tanks remained "on" and therefore the booster pump became operated, as well as because wires of No.2 engine fuel spar valve were burned by fire and the valve was reopened after once closed or not closed fully, and therfore fuel flowed out from the hole on the fuel feed pipe and was ignited by spark due to short circuit of burnt wire bundles.

3.2.3 Fracture of No.2 Engine fuel feed pipe clamp

As stated in paras. 2.3.2 and 2.13.5, at the time of investigation it was recognized that the bolt head of the outside bolt out of two bolts of No. 2 engine fuel feed pipe clamp was fractured. The result of investigation on the fractured surface by use of a SEM and an X-ray micro-analyser indicated that the whole of the fractured surface was covered with cadmium. There was no deformation by extension at the fractured portion, and on the fractured surface there was found almost no evidence of dimples indicative of a static failure.

It is considered that the bolt was subjected to heat sufficient enough to melt its cadmium plating, and the difference in heat expansion rate of the spacer (of an aluminum) and the bolt (of a steel) caused a tensile stress due to heat expansion to the bolt, generating cadmium embrittlement with the result that the bolt was fractured without deformation by extension. It is also considered that after the fracture of the bolt, the melted cadmium adhered to the fractured surface.

Since as stated in para.3.2.1 a large-scale fire would not have occurred in flight, it would be at the time of fire after landing that the bolt head was fractured being subjected to heat.

3.2.4 EICAS messages which were recorded in CMC

Causes for display of various EICAS messages which were recorded in CMC as stated in para. 3.1.1 are estimated to have been as follows:

(1) Display cause for most of EICAS messages are estimated to have been burn of wires of systems due to fire which occurred within the left wing leading edge (ILES630～693). It is estimated that most of the messages were displayed by a false signal due to the burn of wires, and malfunctions did not really occur, but some of them would have indicated a real malfunction of systems caused by burn of wires.

(2) In CMC it was recorded that fault on FMC occurred 43 times in total during a period from the 13th flight before this accident until the previous flight. However, in the maintenance record, there was found no description that corrective measures were taken for these malfunctions. It is estimated that the same temporary malfunction occurred on FMC as in the past flights occurred on this accident flight, and EICAS messages concerning autopilot and autothrottle were displayed. It is noted that these messages would be shown even in case output bus wires were burnted and short-circuited by fire.

(3) It is estimated that messages on the engine fire extinguishing system were caused by execution of engine extinguishing measures.

The EICAS messages stated above are grouped by level of message and are listed in Tables 4～6 below, showing their probable display cause and probable malfunction of the system. Marks A, B, and C in the column of the probable display cause correspond items (1),(2), and (3) above, respectively.

Table 4 Probable cause of display and malfunction of Caution Messages which were recorded in CMC

EICAS Message	Time displayed (UTC)	Probable Cause of Display	Probable Malfunction
BLD DUCT LEAK L	0921	A	Due to wire burn, false signal of bleed air leak was generated
FLAPS PRIMARY	0921	A	Due to wire burn, primary pneumatic mode of leading edge flaps became inoperative and switched over to primary electrical mode
OVHT ENG 1 NAC	0921	A	Due to wire burn, false signal of overheat within nacelle of No.1 engine was generated (INT)
FLAPS DRIVE	0921	A	Due to wire burn, primary electrical mode of leading edge flaps became inoperative
>AUTOTHROT DISC	0923	B	FMC was brought in resynchro mode due to temporary failure of FMC (INT)
>AUTOPILOT	0923	B	FMC was brought in resynchro mode due to temporary failure of FMC (INT)

Table 5 Probable cause of display and malfunction of

Advisory Messages which were recorded in CMC

EICAS Message	Time displayed (UTC)	Probable Cause of Display	Probable Malfunction
ELEC DRIVE 1	0921	A	Due to wire burn, false signal of fall in oil pressure or rise in oil temperature of No.1 IDG was generated (INT)
ENG 1 FUEL VLV	0921	A	Due to wire burn, false signal of actuation of No.1 Engine Fuel Spar Valve was generated
>FUEL JETT B	0921	A	Due to wire burn, inoperation of B System of Fuel Jettison System
ELEC GEN OFF 1	0921	A	Due to burn of wire for detection of input speed of No.1 IDG, false signal of decrease in input speed was generated, and No.1 IDG was separated from No.1 AC power bus by actuation of protective circuit
>JETT NOZZLE L	0921	A	Due to wire burn, false signal of actuation of Left Wing Fuel Jettison Nozzle Valve was generated

NAI VALVE 1	0921	A	Due to wire burn, false signal of actuation of No.1 Engine Nacelle Anti-Ice Valve was generated (INT)
FUEL X FEED 1	0922	A	Due to wire burn, false signal of actuation of No.1 Tank Fuel Cross-feed Valve was generated
>FMC MESSAGE	0923	B	Due to temporary failure of FMC, FMC was brought in resynchro mode (INT)
ENG 1 EEC MODE	1031	A	Due to wire burn, primary mode of No.1 Engine EEC became inoperative, and switched over to alternate mode
>NO LAND 3	1032	B	False signal due to burn of wires from FMC to EEC was generated
>BTL LO ENG B	1032	C	Use of Extinguisher Bottle of B system for left engines (not system malfunction)
ENG 2 FUEL VLV	1034	A	Malfunction of Fuel Spar Valve and Fuel Metaling Unit's shut-off valve due to wire burn
>BTL LO L ENG A	1032	C	Use of Extinguisher Bottle of A system for left engines (not system malfunction)

Table 6 Probable cause of display and malfunction of Satus Messages which were recorded in CMC

EICAS Message	Time displayed (UTC)	Probable Cause of Display	Probable Malfunction
FUEL SPAR VLV 1	0921	A	Due to wire burn, false signal of actuation of Fuel Spar Valve was generated
NAI DUCT 1 LEAK	0921	A	Due to wire burn, false signal of leak of bleed air from nacelle anti-ice duct of No.1 Engine was generated (INT)
FLAP SYS MONITOR	0921	A	Due to wire burn, false signal of failure of Flap Control Unit or leading edge flap position sensor was generated
FUEL JETT B	0921	A	Due to wire burn, B system of fuel jettison became inoperative
ELEC GEN SYS 1	0921	A	Due to wire burn input speed of No.1 IDG decreased, oil pressure of IDG decreased, and false signal of failure of oil temperature sensor generated

ENG 1 OVHT LP B	0921	A	Due to wire burn, false signal of No.1 Engine overheat was generated
ENG 1 EEC C1	0921	A	Due to wire burn, failure of category 1 occurred to EEC
ADC LEFT	0921	A	Due to wire burn of ADC#3 output bus to EEC, false signal of ADC failure generated
ADC RIGHT	0921	A	same as above
BLEED ASCTU A	0921	A	Due to wire burn, false signal of failure of Channel A of Bleed Air Supply Control and Test Unit (ASCTU) was generated
FUEL QTY SYS	0921	A	Due to wire burn, false signal of failure of Fuel Quantity System was generated
JETT NOZZLE L	0921	A	Due to wire burn, false signal of failure of Left Wing Fuel Jettison Nozzle Valve was generated
LE MULT DRIVE	0921	A	Due to wire burn, false signal of failure of Leading Edge Flap Drive was generated
BLD DUCT LEAK L	0921	A	Due to wire burn, false signal of bleed air leak

			was generated
ELEC DRIVE 1	0921	A	Due to wire burn, false signal of fall in oil pressure or rise in oil temperature of IDG was generated (INT)
ENG 1 OVHT LP A	0921	A	Due to wire burn, false signal of No.1 Engine overheat was generated
ANTI-ICE NAC 1	0921	A	Due to wire burn, false signal of failure of No.1 Engine NAI valve or NAI Pressure Regulator was generated
FUEL X FEED 1	0922	A	Due to wire burn, false signal of failure of No.1 Tank Fuel Cross-feed Valve was generated
ENG 1 EEC MODE	1031	A	Due to wire burn, primary mode of No.1 Engine EEC became inoperative, and switched over to alternate mode
GROUND PROX SYS	1031	A	Input of false information on flap position to Ground Proximity Warning System
BTL LOW L ENG B	1032	C	Use of Extinguisher Bottle of B system for left engines (not system malfunction)

FUEL SPAR VLV 2	1034	A	Due to wire burn, malfunction of Fuel Spar Valve and Fuel Metaling Unit's shut-off valve
BTL LOW L ENG A	1035	C	Use of Extinguisher Bottle of A system for left engines (not system malfunction)

3.2.5 Malfunction of cabin pressurization system

(1) Inoperative auto-control of cabin pressurization

As stated in para. 3.1.1, CMC recorded a status message indicating that the left and the right air data computer (ADC) were inoperative from about 0921 UTC until the power source of the aircraft was cut off. It is estimated that this message was displayed due to wire burn and short circuit of #3 bus passing from ADC to EEC caused by fire which occurred within the leading edge of the left wing. It is further estimated that thereby the auto-control of the cabin pressurization controller became inoperative and the caution message 《CABIN ALT AUTO》 was displayed on EICAS as stated by the flight crew. However, it is estimated that this message was not recorded in CMC because the failure was not of the cabin pressure controller (CPC) having the auto-control function.

It is estimated that about 0921 UTC caution messages 《BLEED DUCT LEAK L》 and 《OVHT ENG 1 NAC》 were also displayed on EICAS, and the flight crew brought the bleed isolation valve to "off" and the bleed air switch of No.1 and No.2 engine to "off". Moreover, in DFDR it was recorded that No.1 and No.2 air conditioning pack were brought "off".

It is estimated that up to about 0921 UTC the Cabin Pressure Controller was controlling cabin pressurization by adjusting volume of flow-out air at the opening of outflow valve corresponding to operation by three air conditioning packs, but the valve came to a stop at the position at the time the auto-control became inoperative.

It is estimated that since the No.1 and No.2 air conditioning pack were brought to "off" at this time, and therefore the system became one-pack operation, the flow-in air reduced, with the result that the flow-out air became more than the flow-in air to decrease the cabin pressure and increase the cabin altitude. The flight crew became aware of this irregularity, made the aircraft to descend, and operated manually the outflow valve, but the cabin pressure continued to decrease and the cabin altitude warning system was actuated.

It is estimated that the outflow valve was closed manually about 0927 UTC. And immediately thereafter the cabin pressure turned to increase and the cabin altitude to decrease. It is considered that the rate of descent of the cabin altitude increased further because No.2 pack was brought again to "on" about 0942 UTC.

Thereafter the cabin pressure did not increase. It is estimated that it is because the opening of the outflow valve was adjusted manually. After about 0943 UTC, the cabin pressure repeated variation within a small range at about 17 psia (equivalent to a cabin altitude of minus 4,000 ft when converted to the standard atmosphere. The same applies hereinafter).

As mentioned in para. 2.1, the flight crew stated that they were operating manually the outflow valve but the pointer of the instrument to indicate valve position became stuck (right side: at full-close left side: at 1/8 open) after a certain point of time and also that as stated in para. 3.1.1, the advisory message 〈OUTFLOW VALVE L,R〉 was shown on EICAS although their memory was uncertain. The said message is a message to be shown in case the outflow valve auto-control failed or the manual control was commanded. However, since in CMC there is no record left on display of the message, it is estimated that the message was displayed because the manual control was commanded. It is estimated that there were no failures involved of the manual control because it was normally operated, as stated in para. 2.12.2, in the operation attempted again in the emergency evacuation. A possibility is conceivable that the manual control would have became temporarily inoperative in flight, when taking into account the cabin altitude shifting as low as minus 4000 ft, but it could not be clarified.

Moreover, as stated in para. 2.13.1, judging from the position of the outflow valve manual switch and the position of the outflow valve of the aircraft found by an investigation after the accident, it is conceivable that only left-side outflow valve was being operated manually with the right-side outflow valve kept close.

The cabin pressure was 17.0 psia (equivalent to a cabin altitude of approximately minus 4,000 ft) at 1031 UTC when touch-down was made, and the atmospheric pressure at the airport at that time is estimated as approximately 14.2 psia. Therefore, difference between the cabin pressure and the outer atmospheric pressure was approximately 2.8 psi, exceeding considerably the maximum differential pressure of 0.11 psi which is an operating limitation for takeoff and landing. The cabin pressure at the time the emergency evacuation directed was 16.8 psia (equivalent to a cabin altitude of approximately minus 3,800 ft) with a differential pressure of approximately 2.6 psi. For this reason, it is estimated that door handles would have been hardly moved, and time was required to open them.

As stated in para.2.12.2, when time was required to open doors in the emergency evacuation, the captain who was told from the alternate captain about the status in the cabin, tried to open manually the outflow valve, but only a left-side outflow valve was actuated, and therefore time would have been required to depressurize the cabin. (The outflow valve is driven by an AC motor (115 V) in case of auto-control, but in case of manual control by a DC motor (28 V). The DC power is supplied from the main battery after engines and APU are shut down. Time required to "full open" the valve from "full close" the valves by the DC motor is approximately 30 seconds.)

The status of the cabin pressurization system can be displayed on EICAS for the flight crew to comprehend the cabin altitude, differential pressure with the outer atmosphere, etc., but the cabin altitude indication is limited to minus 1000 ft. Therefore it is necessary for the crew to calculate it from the flight altitude and differential pressure when they would comprehend the cabin altitude descended to down to minus 4000 ft.

(2) Rise in cabin temperature

As stated in paras. 2.1 and 2.12.3, according to the crew, about the time cabin pressure decreased, the cabin temperature increased.

It is estimated that, as stated in the preceding paragraph, the cabin temperature increased because the air conditioning system became one-pack operation, flow-in air become less than flow-out air, and an appropriate cabin temperature control became difficult.

3.2.6 Display of malfunction of leading edge flaps

As stated in para. 2.1, according to the flight crew, about 0921 UTC while the aircraft was climbing, caution messages 〈FLAPS PRIMARY〉 and 〈FLAPS DRIVE〉 were displayed on EICAS, the expanded display of the leading edge flaps was also displayed indicating failure of the position sensor of the outboard and the midspan leading edge flaps group of the left wing as well as stoppage in transit of the inboard and the midspan leading edge flaps group of the right wing.

It is estimated that with regard to the left wing this was caused by burn of wires to the position sensor of the leading edge flaps by the fire which occurred within the leading edge (ILES630～693). With regard to the right wing, display cause of the expanded display and its relationship with the fire were not clarified.

Flaps manipulation was carried out in landing approach, but the leading edge flap system, as stated in para. 2.13.1, only part of groups of the right wing were somewhat drooped, and other leading edge flaps were retracted.

From the above, it is estimated that the leading edge flaps became inoperative.

3.2.7 Actuation of stick shaker

As stated in para. 3.1.2, according to DFDR, during a period from about 0923 UTC to 0924 UTC, the stick shaker was actuated 5 times in total at an altitude of approximately 27,000～26,000 ft and within a CAS range of 245～258 knots.

Moreover, as stated in para. 2.1, according to the flight crew, around the time the stick shaker was actuated, the maximum speed bar and the minimum speed bar in the speed display of PFD came close to, and sometimes overlapped each other.

From a system-wise view point, the stick shaker is not equipment which does monitor the airspeed and is actuated when it approached the stalling speed, but it is actuated when the vane angle, the angle of attack of the aircraft adjusted for the pitch rate of the fuselage, exceeded the trip angle.

Since it is estimated from DFDR record that the vane angle exceeded the trip angle when the stick shaker was actuated, it is estimated that the stall warning system was in normal operation.

On the other hand, as stated in para. 2.1, the flight crew witnessed that around this time the maximum speed bar and the minimum speed bar approached, and overlapped one another at times in the speed display of PFD.

It is estimated that this is because wires related to the leading edge flaps were burned by the fire within the left wing leading edge (ILES630～693), thereby a false signal of Flap 5, the maximum speed bar of PFD lowered from the maximum speed (Vmo/Mmo) in the flap-up condition to the flap placard speed of flap 5 (260 knots), and, on the other hand, since the minimum speed bar with flaps up was being displayed, both speed bars approached or overlapped each other.

3.2.8 Malfunction of autothrottle and autopilot

As stated in para. 2.1, according to the flight crew, about 0923 UTC the autothrottles were disconnected to keep climb power because throttle levers indicated an abnormal move to retard to the idle position.

It is estimated that the autothrottles retarded the throttle levers to the idle position to reduce speed, because, as stated in the paragraph above, a flap placard speed of flap 5 (260 knots) was displayed as the maximum speed and the aircraft was in flight at a CAS of approximately 300 knots around this time. It is also estimated that thereafter the autothrottles became unusable, because, as shown in para. 3.2.4, FMC failed temporarily, and wiring of the electronic engine control system (EEC) of No. 1 engine was burned.

As stated in para. 3.1.2, from DFDR record, it is estimated that even after 0921 UTC at which a series of malfunctions occurred, the autothrottle was sometimes in the connected condition, but the reason therefor is unknown.

Furthermore, as stated in paras. 2.1, 3.1.1 and 3.1.2, it was said that the autopilot was disengaged by the flight crew at about 09:25 UTC. It is estimated that this was because FMC failed temporarily as shown in para. 3.2.4. It was said that the autopilot returned to normal afterwards.

3.2.9 Other malfunctions

(1) Engine overheat

As stated in para.3.1.2, DFDR recorded overheat of No. 1 engine during a period from 0922:05 UTC until termination of DFDR record. It is estimated that this was caused by a false signal due to burn of No. 1 engine fan case overheat switch wire by the fire which occurred within the left wing leading edge (ILES630～693) in the same manner as EICAS caution message 〈OVHT ENG 1 NAC〉 shown in para. 3.2.4 Table 4.

(2) Malfunction of wing anti-ice

As stated in para.3.1.2, DFDR recorded that the wing anti-ice system was "on" during a period from 0921:31 UTC until termination of DFDR record. It is estimated that this was caused by a false signal due to burn of wiring of the wing anti-ice system by the fire which occurred within the left wing leading edge (ILES630～693).

(3) Malfunction of engine thrust reverser

As stated in para. 2.1, according to the flight crew, "REV" in amber to indicate that the thrust reverser of No.1 engine is unlocked was shown on EICAS. Moreover, as stated in para.3.1.2, DFDR record indicated that the thrust reverser of No.1 engine was in transit from 0921 UTC until DFDR record terminated.

Since it was witnessed that the aircraft was not subjected to any yawing nor buffeting, it is estimated that this was caused by a false signal due to burn of wiring of the switch to detect whether the cowl of the thrust reverser is fully deployed or stowed by the fire which occurred within the left wing leading edge (ILES630~693).

3.2.10 Cabin Pressure Control by flight crew

As stated in paras. 2.1 and 3.2.5, the auto-control of the cabin pressurization system of the aircraft failed and the system was being manually controlled in flight, and cabin pressure remained at the time of landing. For this reason, time was required to open doors in the emergency evacuation.

As an operating limitation of the aircraft, the maximum differential pressure between the cabin pressure and the outer atmospheric pressure is prescribed, and depressurization is a prerequisite to opening doors prior to emergency evacuation. It is considered that accurate comprehension of cabin pressure prior to landing as well as execution of procedures prescribed on the outflow valves both in flight and in emergency evacuation should have been done, because even if the outflow valves were stuck, it might be a transient fault.

3.2.11 Emergency evacuation

As stated in paras. 2.1, 2.12.3, 2.12.4 and 3.2.10, it is considered that time was required to open doors due to remaining cabin pressurization and the vicinity of doors was considerably crowded at the time the emergency evacuation was directed. R1, R2, R4, R5, and L1 doors were used for evacuation. It is considered that passengers seated in the middle of the cabin would have been panic-stricken because they were located farthest from evacuation doors, and observed the fire flame.

It is estimated that at doors from where a number of confused passengers evacuated, they would have scrambled to the escape slide, and some of them collided with the paved surface or crushed each other when landing to sustain injury.

Witness of the crew was obtained that extinguisher which fell on the slide made it more slippery, but it is unknown how the extinguisher affected slipperiness of escape slides.

4 Conclusions

4.1 Summary of Analysis

4.1.1 The flight crew were properly qualified, and had valid medical certificates.

4.1.2 The aircraft had a valid airworthiness certificate, and had been maintained and inspected as prescribed.

4.1.3 Clearance between No.2 engine fuel feed pipe and No.1 generator feeder cable, installed on the upper portion of No.2 engine pylon strut within the left wing leading edge, was as narrow as 6 mm as indicated by a post-accident inspection.

It is estimated that due to such an insufficient clearance, the pipe and the cable made contact to each other, and chafing was caused between them by bent of wings and vibration of the feeder cable in flight.

4.1.4 It is estimated that, as mentioned in the paragraph above, insulation coating of the generator feeder cable was damaged by chafing between the feed pipe and the feeder cable in flight, and thereby arcing was caused to make a hole in the pipe through which fuel was flowed out, and ignited, causing a fire within the left wing leading edge of the aircraft.

4.1.5 The blowout panel on the under surface of the left wing leading edge was missing. It is estimated that it was separated from the aircraft due to high pressure within the left wing leading edge caused by fire which occurred in flight, and also that air current which rushed into the leading edge blew out the fire and prevent it from developing further in flight.

4.1.6 It is recognized that wire bundles, engine fire extinguisher piping, etc. installed within the left wing leading edge were burned by the fire which occurred in the area. It is estimated that due to damage to the generator feeder cable and wire bundles, many EICAS messages including Engine Overheat and Bleed Duct Leak were displayed on EICAS in the cockpit and malfunctions occurred to such systems as generator, leading edge flaps and fuel jettison.

4.1.7 It is recognized that after landing fire occurred two times within the left wing leading edge. It is estimated that the fuel leak still continued, and the fuel was ignited by spark or arcing generated by short circuit of wire bundles damaged by fire in flight at the time the aircraft speed decreased.

4.1.8 The head of No.2 engine fuel feed pipe clamp bolt was fractured. It is considered that the fracture was caused by the fire which occurred after landing.

4.1.9 It is recognized that after malfunctions occurred to the aircraft, the cabin altitude increased, and the cabin altitude warning system was temporarily actuated. It is estimated that this is because the auto-control of the cabin pressurization system became inoperative due to a temporary malfunction of ADC, and one-pack operation was conducted at this point of time.

4.1.10 It is recognized that the cabin pressurization system was controlled manually thereafter, but the cabin altitude turned to decrease on the contrary down to approximately minus 4,000 ft. It is estimated that the reason time was required to open doors at the time of the emergency evacuation was that the cabin pressure was approximately 2.6 psi higher than the outside atmosphere.

It is estimated that doors were made open thereafter because cabin pressurization was released by manual operation of the outflow valves.

4.1.11 It is estimated that some of passengers sustained injury in the evacuation because they collided with the paved surface of the taxiway or crushed each other when landing through the escape slide in the emergency evacuation.

4.2 Probable Cause

This accident involves occurrence of fire on the upper portion of No.2 engine pylon strut within the left wing leading edge and injuries to passengers in emergency evacuation.

It is estimated that occurrence of the fire is attributable to the damage which was caused by chafing between No.2 engine fuel feed pipe and No.1 generator feeder cable due to narrow clearance between them.

It is also estimated that injuries to passengers were caused by their collision with paved surface of the taxiway or their mutual crush when slipping down the escape slide to the ground.

5 References

5.1 Airworthiness Directive of Civil Aviation Bureau, Ministry of Transport(TCD)

5.1.1 On September 20, 1991, the day after the accident, the Civil Aviation Bureau, Ministry of Transport issued a TCD (TCD-3552-91) and directed users of Boeing 747-400 in Japan to inspect the aircraft for any damage to engine fuel feed pipe within the wing leading edge in order to prevent fire caused by the damage on the fuel feed pipe.

5.1.2 On April 9, 1992, the CAB revised the TCD above and issued it as TCD-3552A-92, by which the CAB for the purpose of preventing malfunctions which cause fire within the engine strut, directed users of Boeing 747-400 that inspection (including the repetitive inspection) and repair, as necessary, be made on the clearance between the fuel feed pipe and the generator feeder cable within the wing leading edge, and suggested modification to fit up support brackets on the feeder cable (see Attached Fig. 10) as an alternate measure of the repetitive inspection. The modification is intended to isolate the fuel feed pipe by installing support brackets to the feeder cable.

Moreover, the Civil Aviation Bureau revised this TCD again on March 3, 1993, and issued it as TCD-3552B-93, in which the Bureau directed installation of support brackets which would dispense with the repetitive inspection.

These TCDs are based on FAA Airworthiness Directive AD92-05-01 and AD92-27-13, respectively.

5.2 FAA Airworthiness Directive (AD)

5.2.1 FAA, on their judgment that fire which occurred on No.2 engine strut of a Boeing 747-400 on September 19, 1991 may have been caused by a hole opened on the fuel feed pipe by electrical arcing due to chafing with the generator feeder cable or other reasons, issued Airworthiness Directive (AD) T91-20-51 on Boeing Model 747-400 series airplanes as of September 24, 1991 directing that the following inspections and repairs be conducted:

(1) to check the fuel feed pipe and the generator feeder cable within No.2 and No.3 engine strut for any damage or chafing.

(2) to check the clearance between the fuel feed pipe and the generator feeder cable and to secure a clearance of more than 0.375 inch (9.53 mm)

(3) to repeat the checks in (a) and (b) above at an interval not exceeding 500 hours in case where the clearance is less than 0.75 inch (19.1 mm), or at an interval not exceeding 1,000 hours in case the clearance is not less than 0.75 inch.

(4) to check the strut drain of all engines, and repeat the check thereafter at an interval not exceeding 1,000 hours.

(5) In case damage was found by the inspection, repairs should be done and the generator feeder cable be removed so that clearance with the fuel feed pipe is more than 0.375 inch.

5.2.2 FAA issued as of March 13, 1992 AD92-05-01, a revision of the AD above, whereby FAA instructed implementation of (1),(2),(3), and (5) of para.5.2.1 above for the purpose of preventing fire in the engine strut, and suggested a modification to install the support bracket to the generator feeder cable as an alternate measure to the repetitive inspection. FAA further revised this AD into AD92-27-13 (effective as of March 1, 1993), in which they directed the installation of the support bracket within 12 months which dispenses with the repetitive inspection. In the directive, minimum clearance is set forth 0.75 inch between the cable, the bracket, and the neighboring bleed duct for the said repair work.

5.3 Service Bulletin (SB) of Boeing Co.

After this accident the Boeing Company issued a Service Bulletin (SB) No.747-24A2168 (as of September 24, 1991) and its revisions (as of Dec. 5, 1991 and as of Sept. 24, 1992), where a case in which fire occurred within No.2 engine strut due to a hole on the fuel feed pipe generated by chafing between the feed pipe and generator feeder cable was referred to as a reason for their issuance. (see Attached Fig. 10)

By Aircraft Accident Investigation Commission

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Member

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August 26,1993

Attached Table　List of EICAS Messages

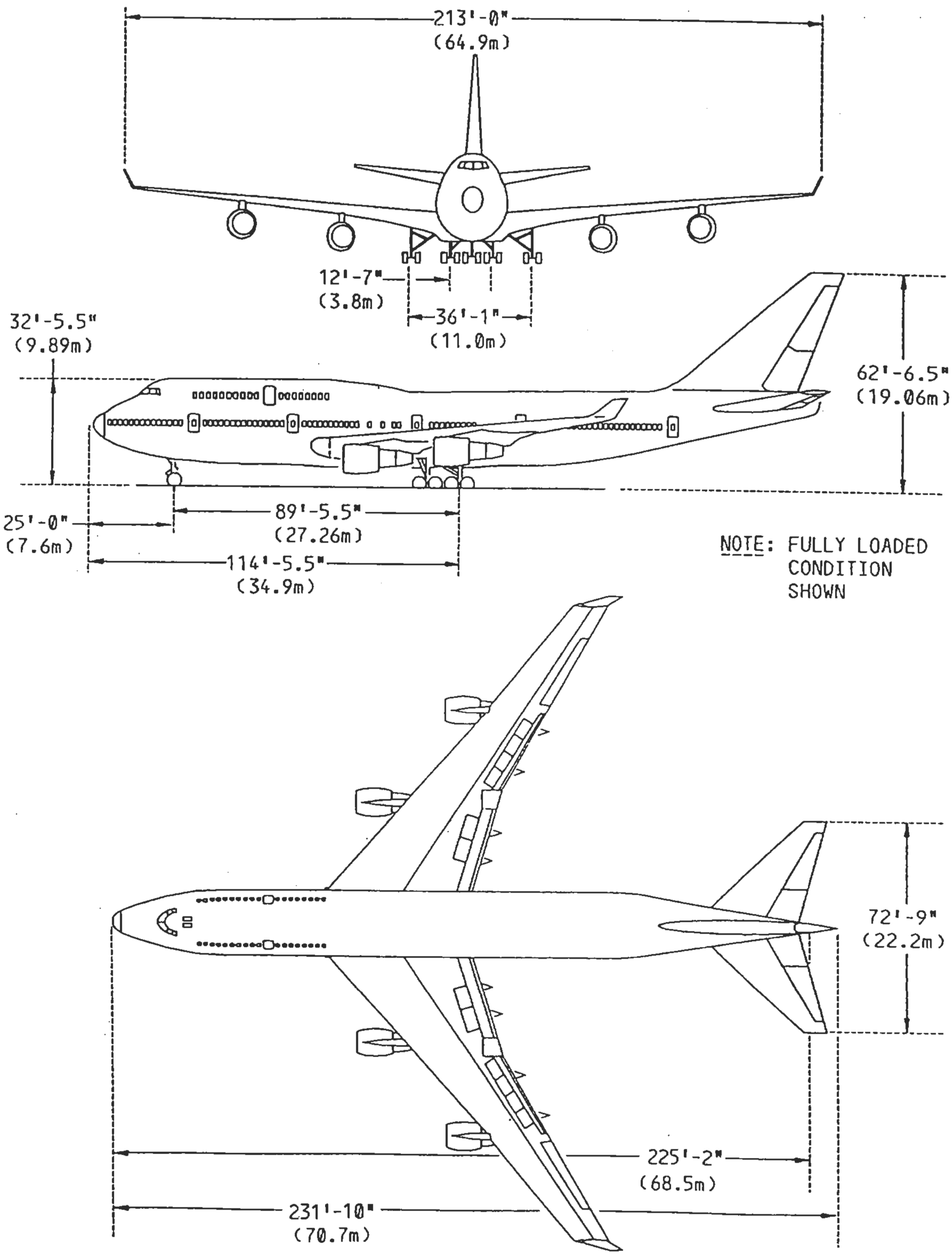
《 EICAS Messages 》	Level	Time (UTC)	Fault Indication
BLEED DUCT LEAK L	C	0921	HARD
ELEC DRIVE 1	A	0921	INT
ENG 1 FUEL VLV	A	0921	HARD
FUEL SPAR VLV 1	S	0921	HARD
NAI DUCT 1 LEAK	S	0921	INT
FLAP SYS MONITOR	S	0921	HARD
>FUEL JETT B	A	0921	HARD
FUEL JETT B	S	0921	HARD
ELEC GEN SYS 1	S	0921	HARD
ENG 1 OVHT LP B	S	0921	HARD
ELEC GEN OFF 1	A	0921	HARD
ENG 1 EEC C1	S	0921	---
ADC LEFT	S	0921	HARD
ADC RIGHT	S	0921	HARD
BLEED ASCTU A	S	0921	HARD
FUEL QTY SYS	S	0921	HARD
FLAPS PRIMARY	C	0921	HARD
OVHT ENG 1 NAC	C	0921	INT
>JETT NOZZLE L	A	0921	HARD
JETT NOZZLE L	S	0921	HARD
LE MULT DRIVE	S	0921	HARD
BLD DUCT LEAK L	S	0921	HARD
NAI VALVE 1	A	0921	INT
ELEC DRIVE 1	S	0921	INT
ENG 1 OVHT LP A	S	0921	HARD
ANTI-ICE NAC 1	S	0921	INT
FLAPS DRIVE	C	0921	HARD
FUEL X FEED 1	A	0922	HARD
FUEL X FEED 1	S	0922	HARD
>AUTOTHROT DISC	C	0923	INT
>FMC MESSAGE	A	0923	INT
>AUTOPILOT	C	0923	INT

Attached Table (Continue)

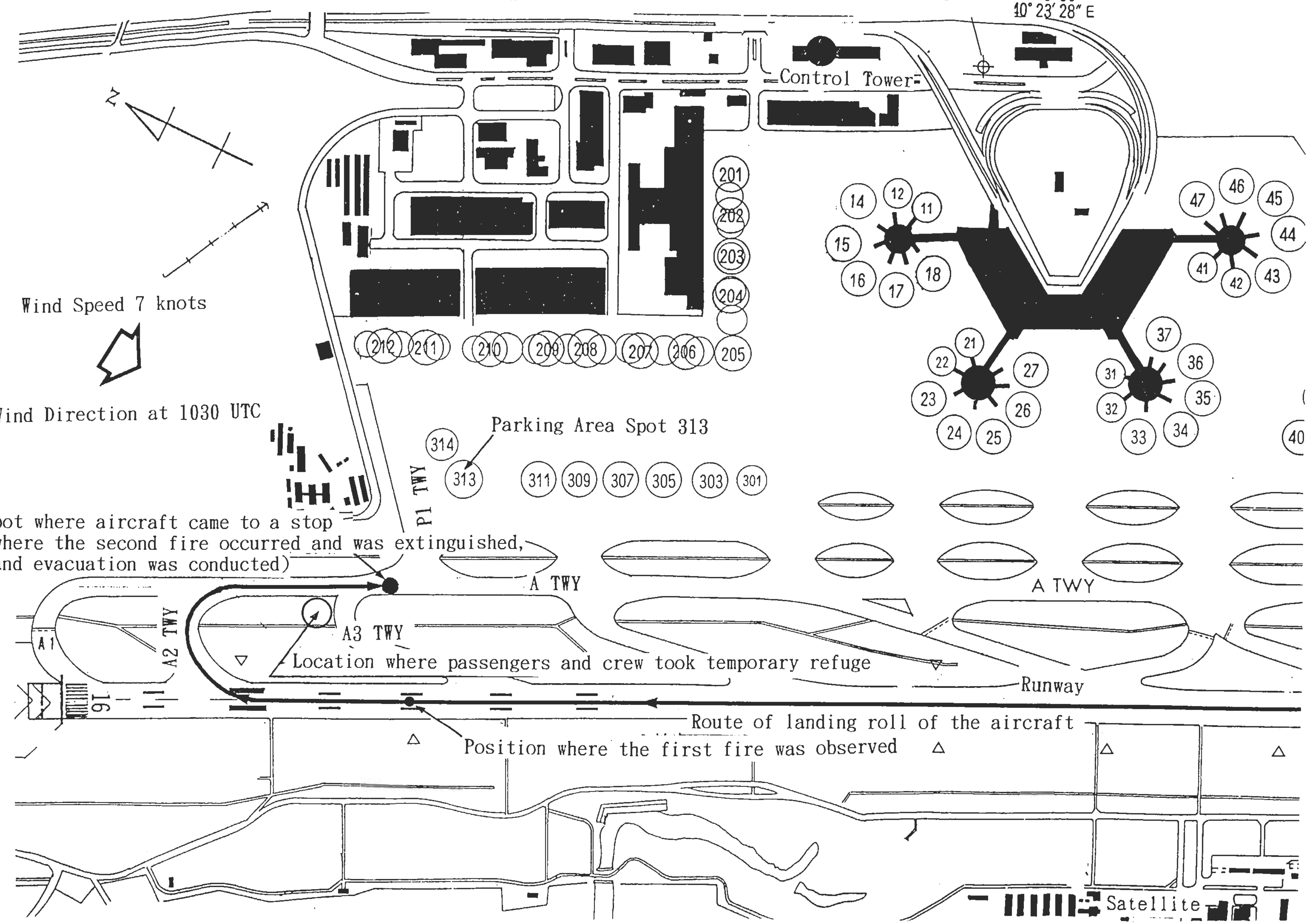
《 EICAS Messages 》	Level	Time (UTC)	Fault Indication
ENG 1 EEC MODE	A	1031	---
ENG 1 EEC MODE	S	1031	---
GROUND PROX SYS	S	1031	HARD
>NO LAND 3	A	1032	HARD
>BTL LO L ENG B	A	1032	HARD
BTL LOW L ENG B	S	1032	HARD
ENG 2 FUEL VLV	A	1034	HARD
FUEL SPAR VLV 2	S	1034	HARD
>BTL LO L ENG A	A	1035	HARD
BTL LOW L ENG A	S	1035	HARD

C:Caution A:Advisory S:Status

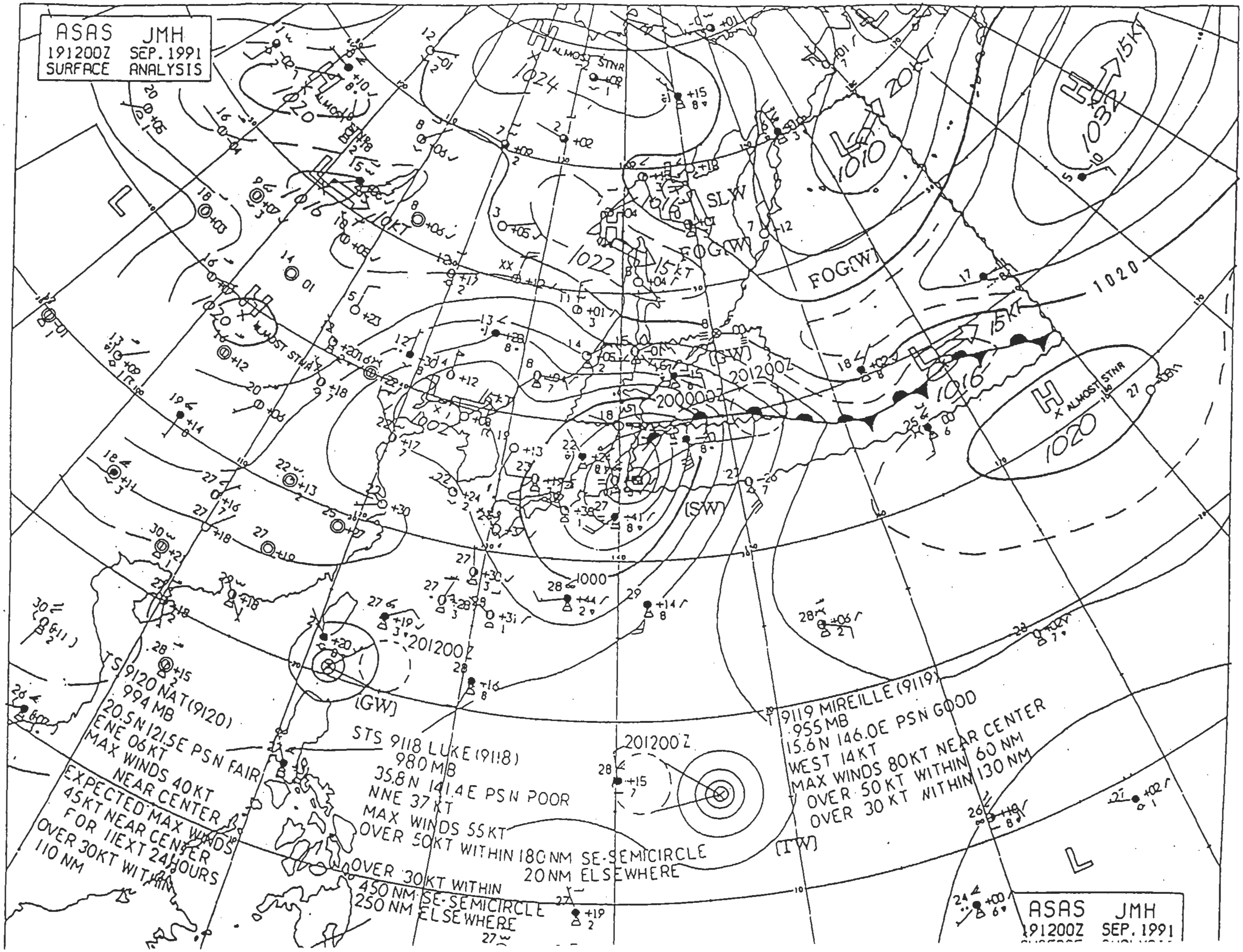
Attached Fig. 1　Boeing 747-400　THREE VIEWS



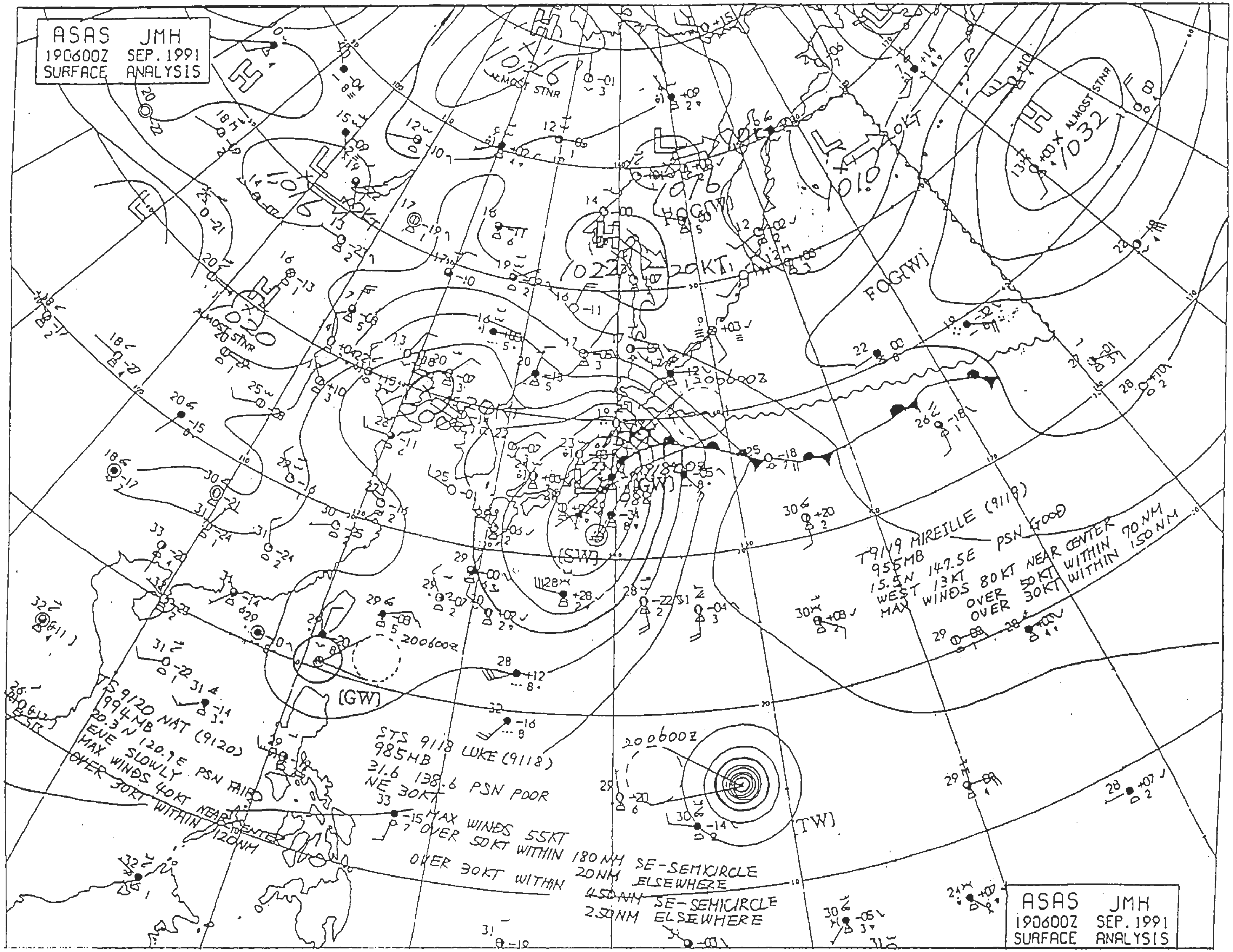
Attached Fig. 2 Taxiing Route of Accident Aircraft at Narita Airport



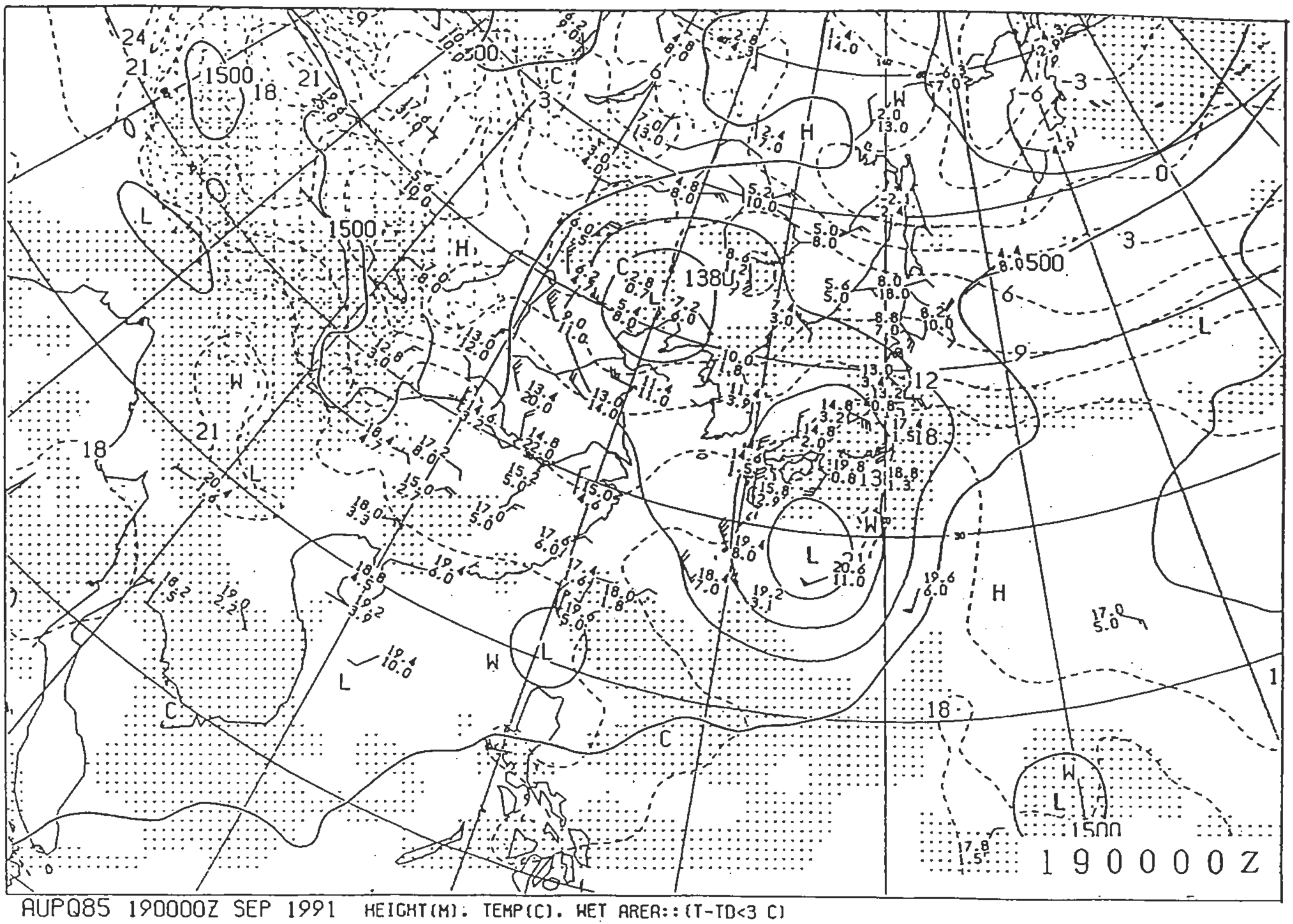
Attached Fig.3 a) Surface Chart (ASAS) 190600Z



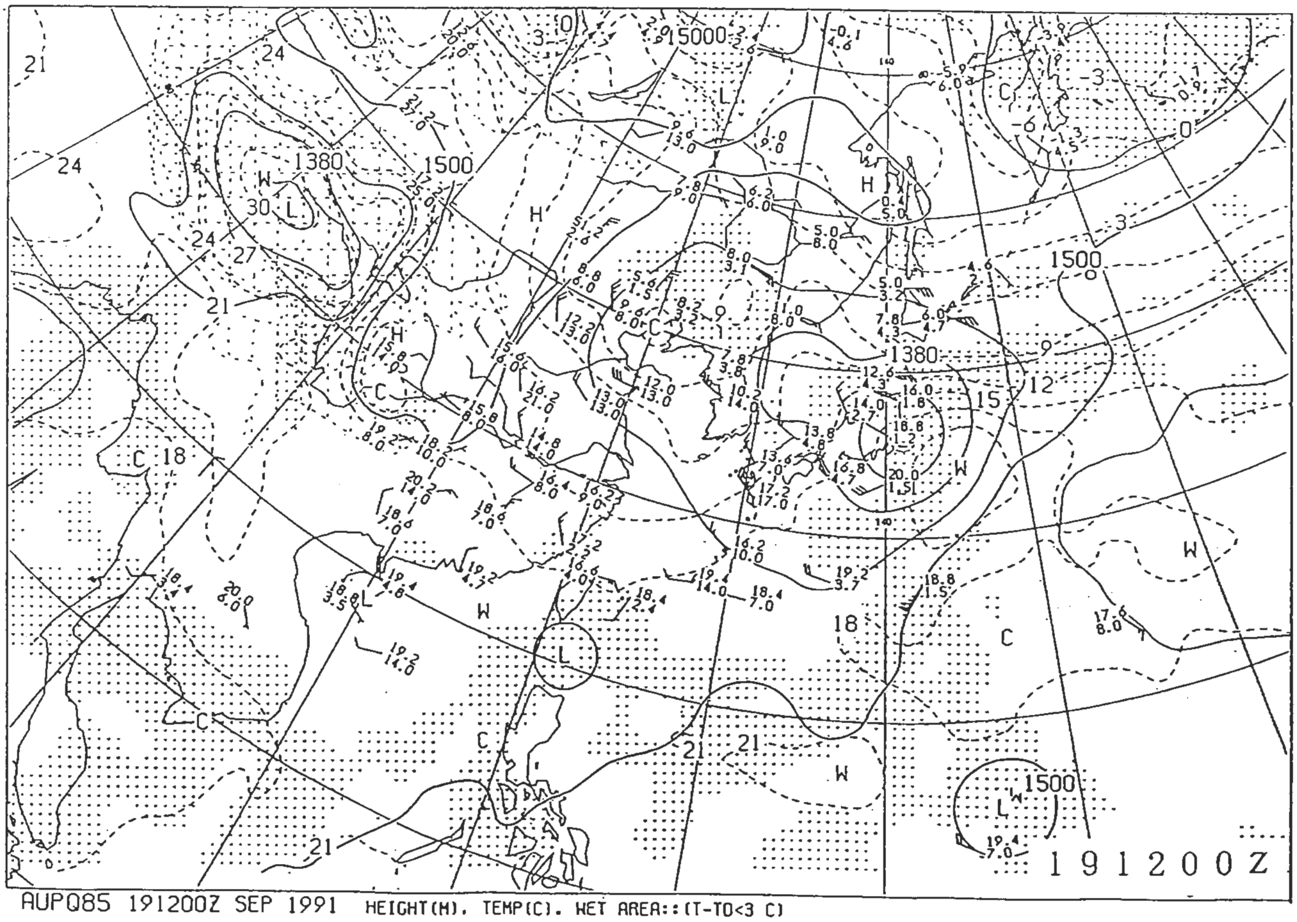
Attached Fig. 3 b) Surface Chart (ASAS) 191200Z



Attached Fig. 4 a) Upper-air Chart 850 hPa

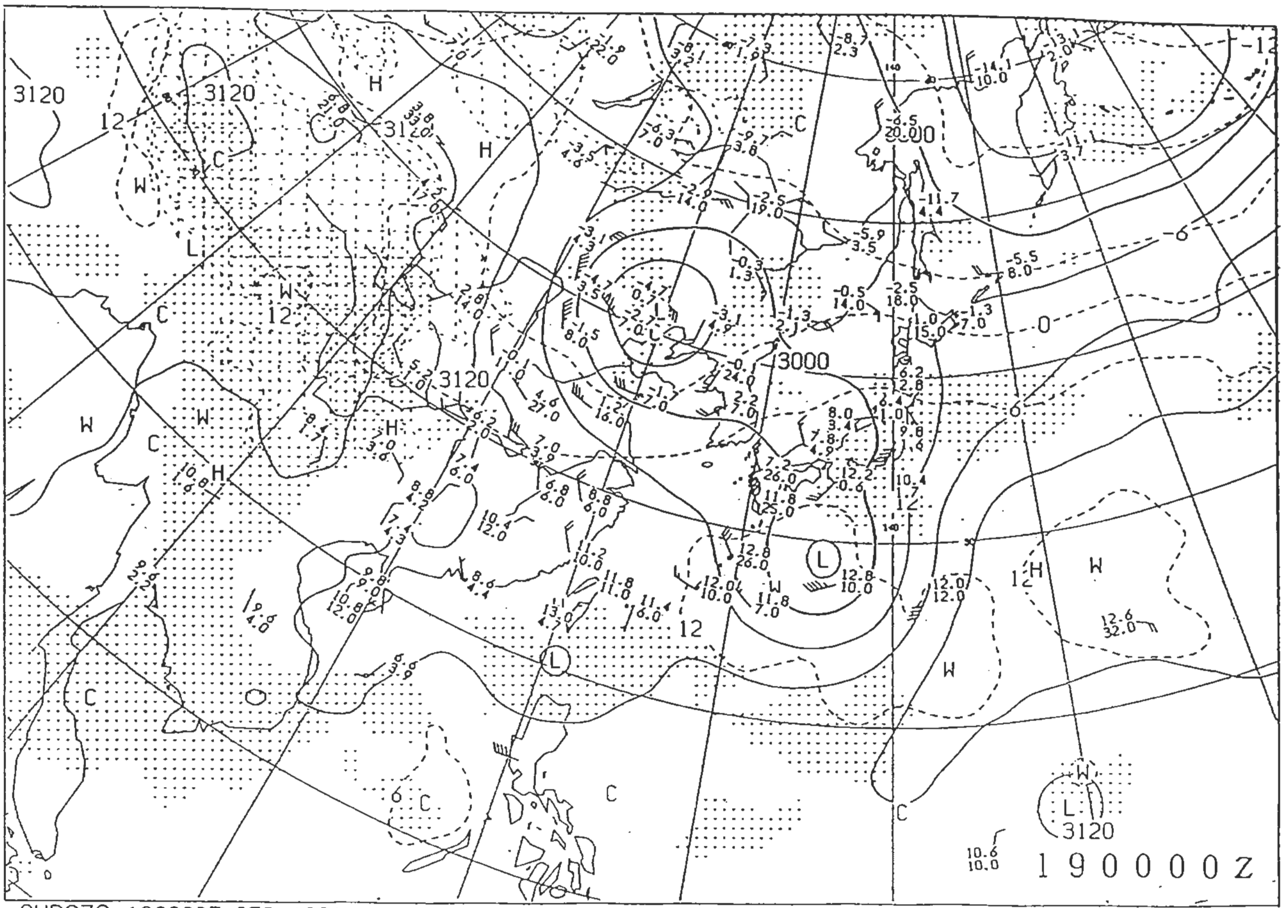


AUPQ85 190000Z SEP 1991 HEIGHT(M). TEMP(C). WET AREA::(T-TD<3 C)

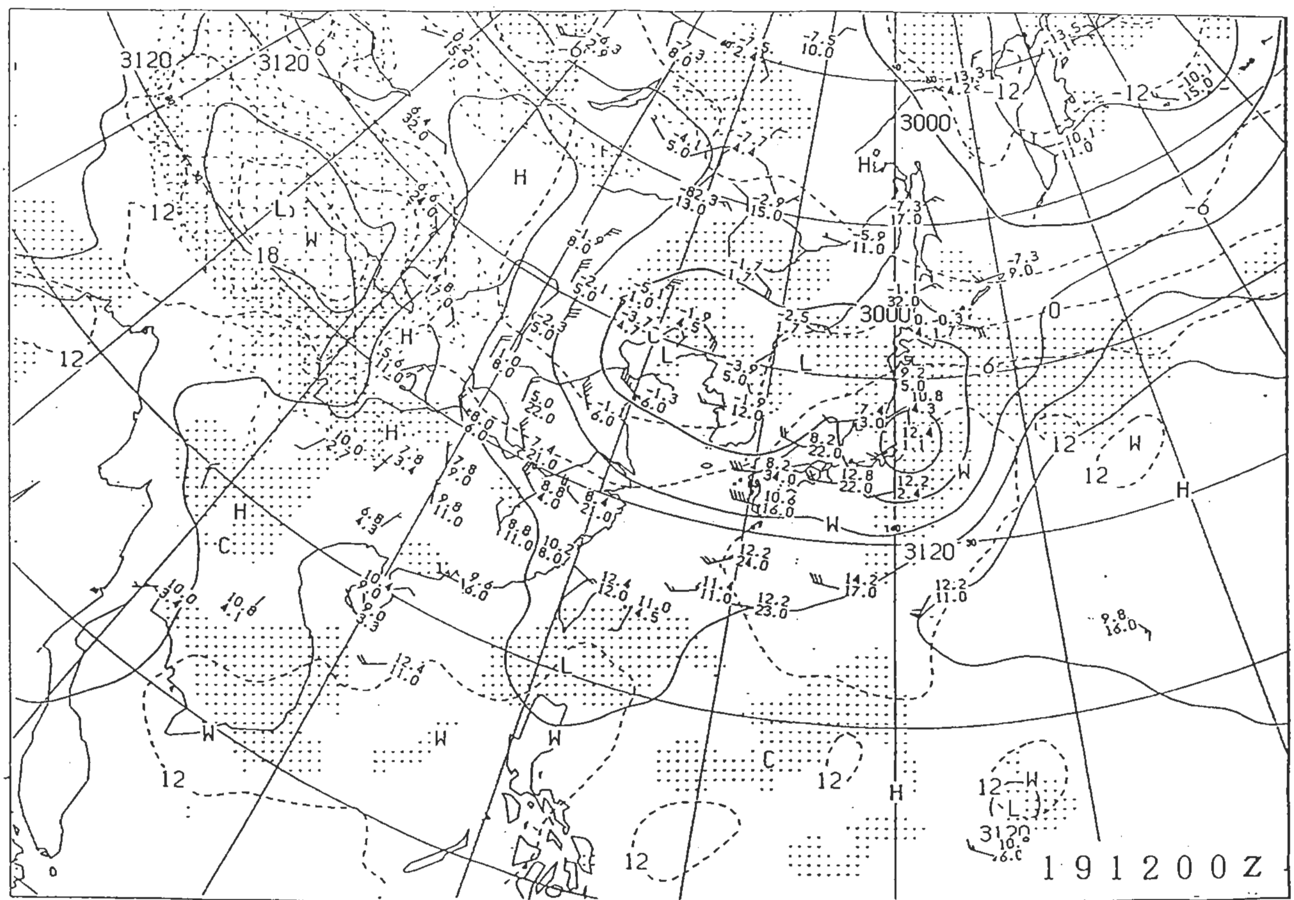


AUPQ85 191200Z SEP 1991 HEIGHT(M). TEMP(C). WET AREA::(T-TD<3 C)

Attached Fig. 4 b) Upper-air Chart 700 hPa

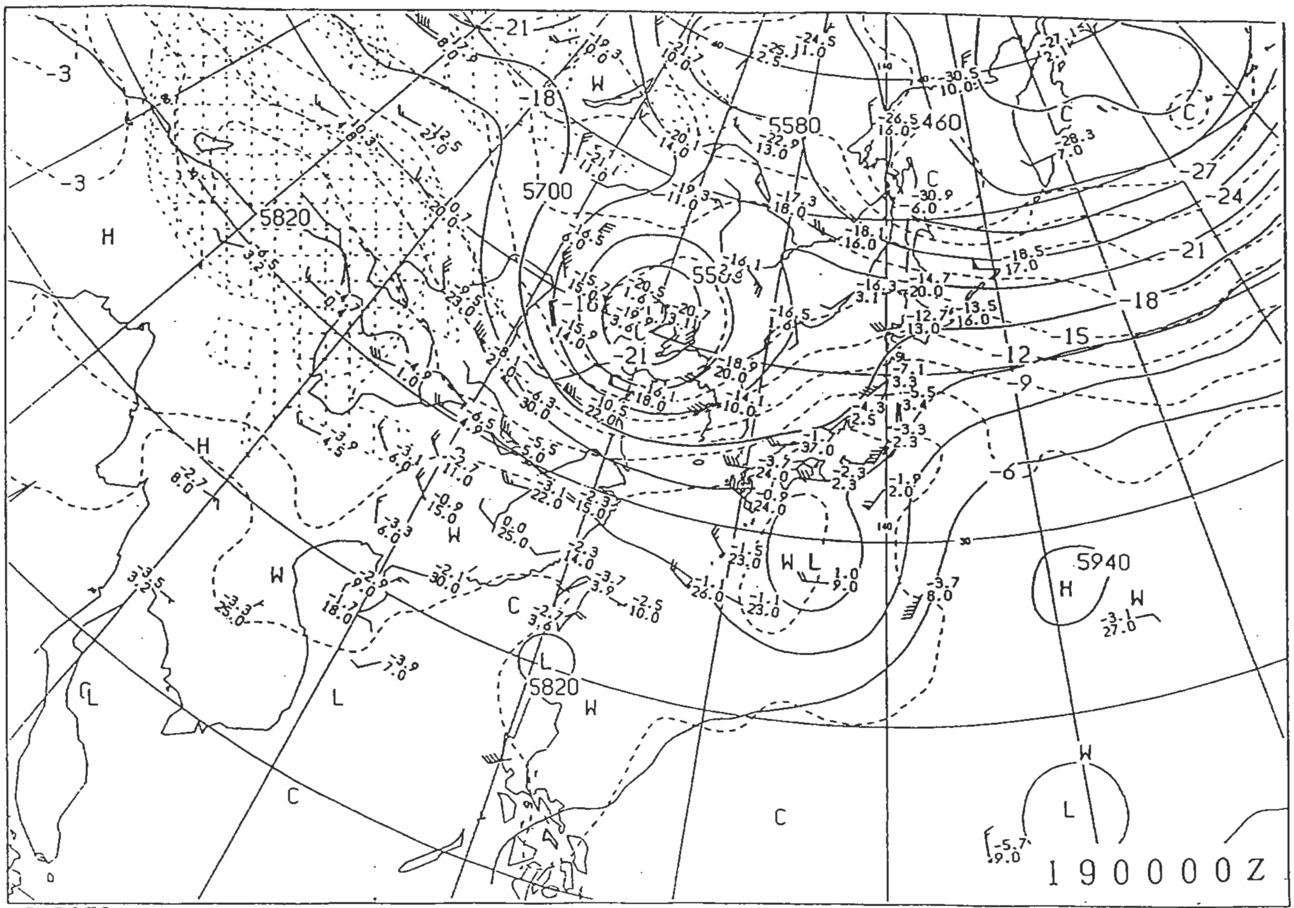


AUPQ70 190000Z SEP 1991 HEIGHT(M). TEMP(C). WET AREA:: (T-TD<3 C)

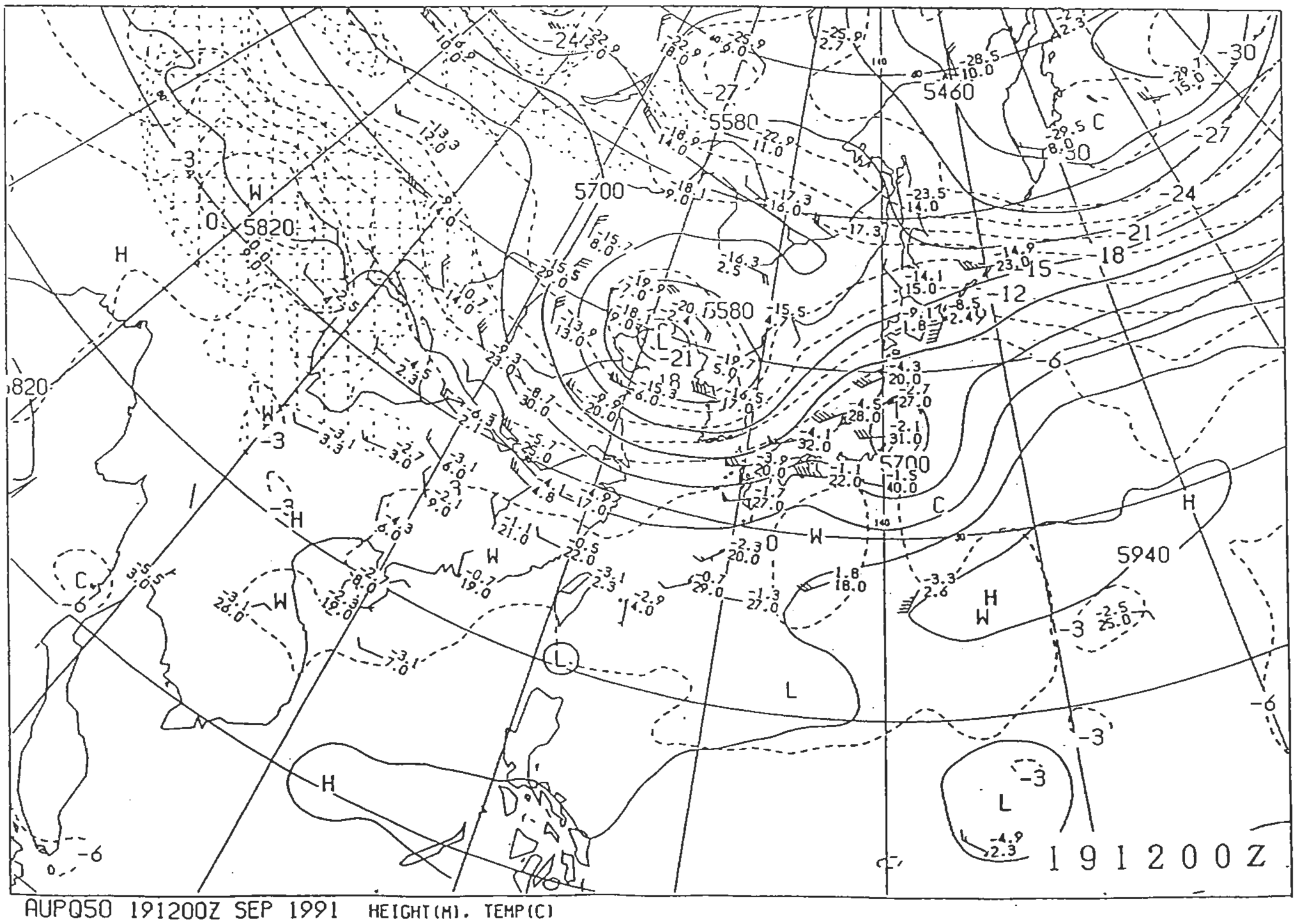


AUPQ70 191200Z SEP 1991 HEIGHT(M). TEMP(C). WET AREA:: (T-TD<3 C)

Attached Fig.4 c) Upper-air Chart 500 hPa

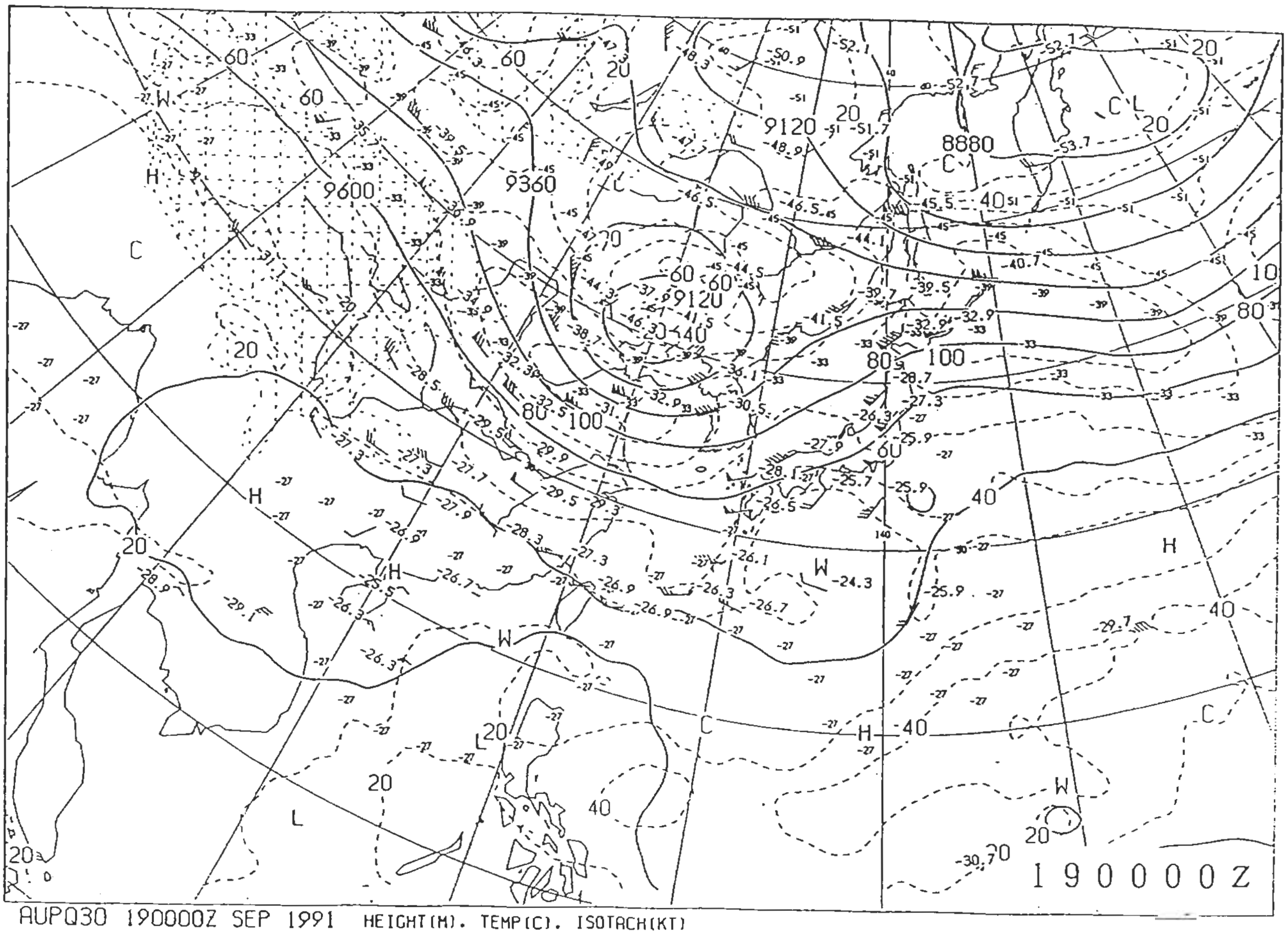


AUPQ50 190000Z SEP 1991 HEIGHT(M). TEMP(C)

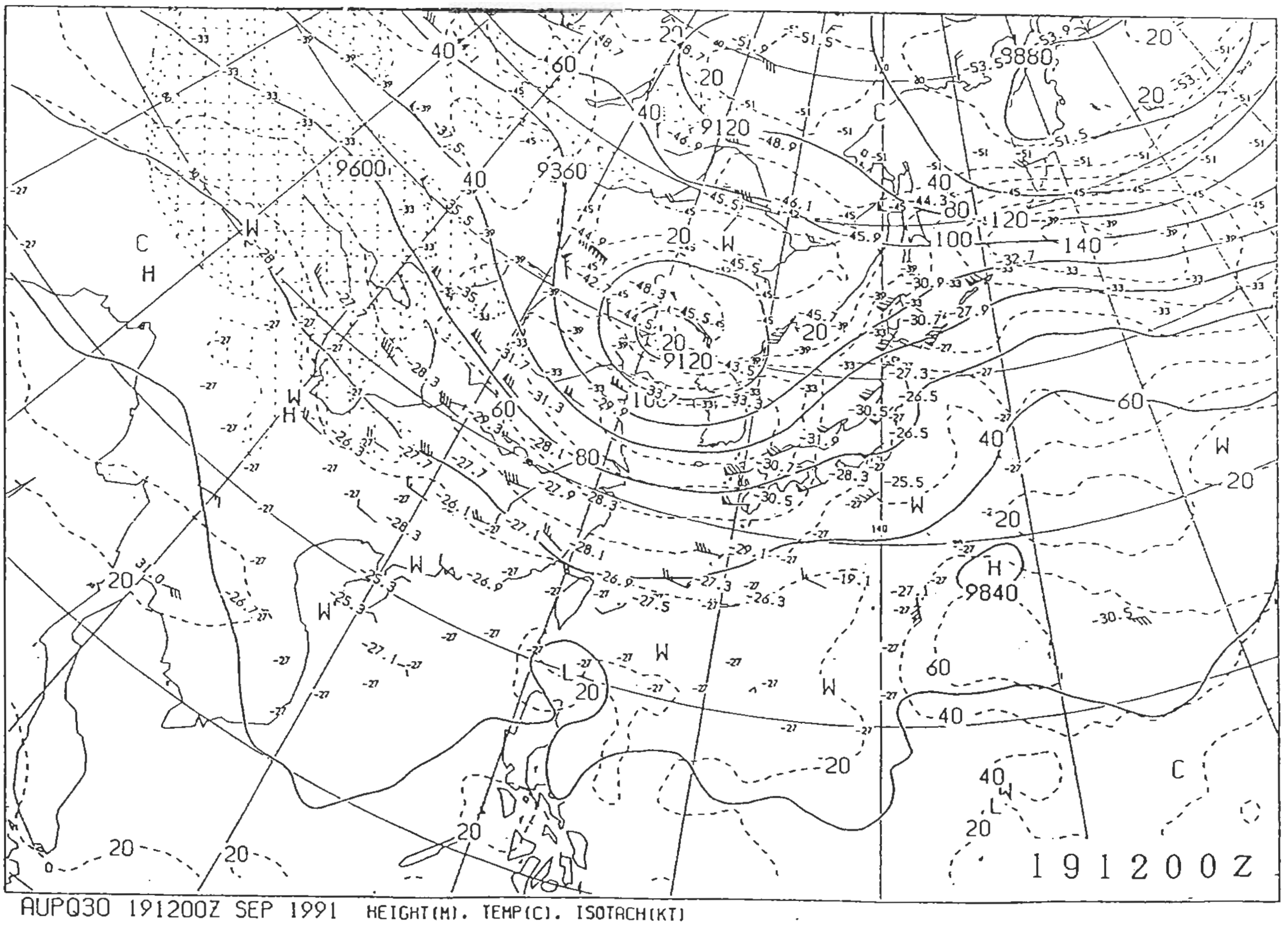


AUPQ50 191200Z SEP 1991 HEIGHT(M). TEMP(C)

Attached Fig. 4 d) Upper-air Chart 300 hPa

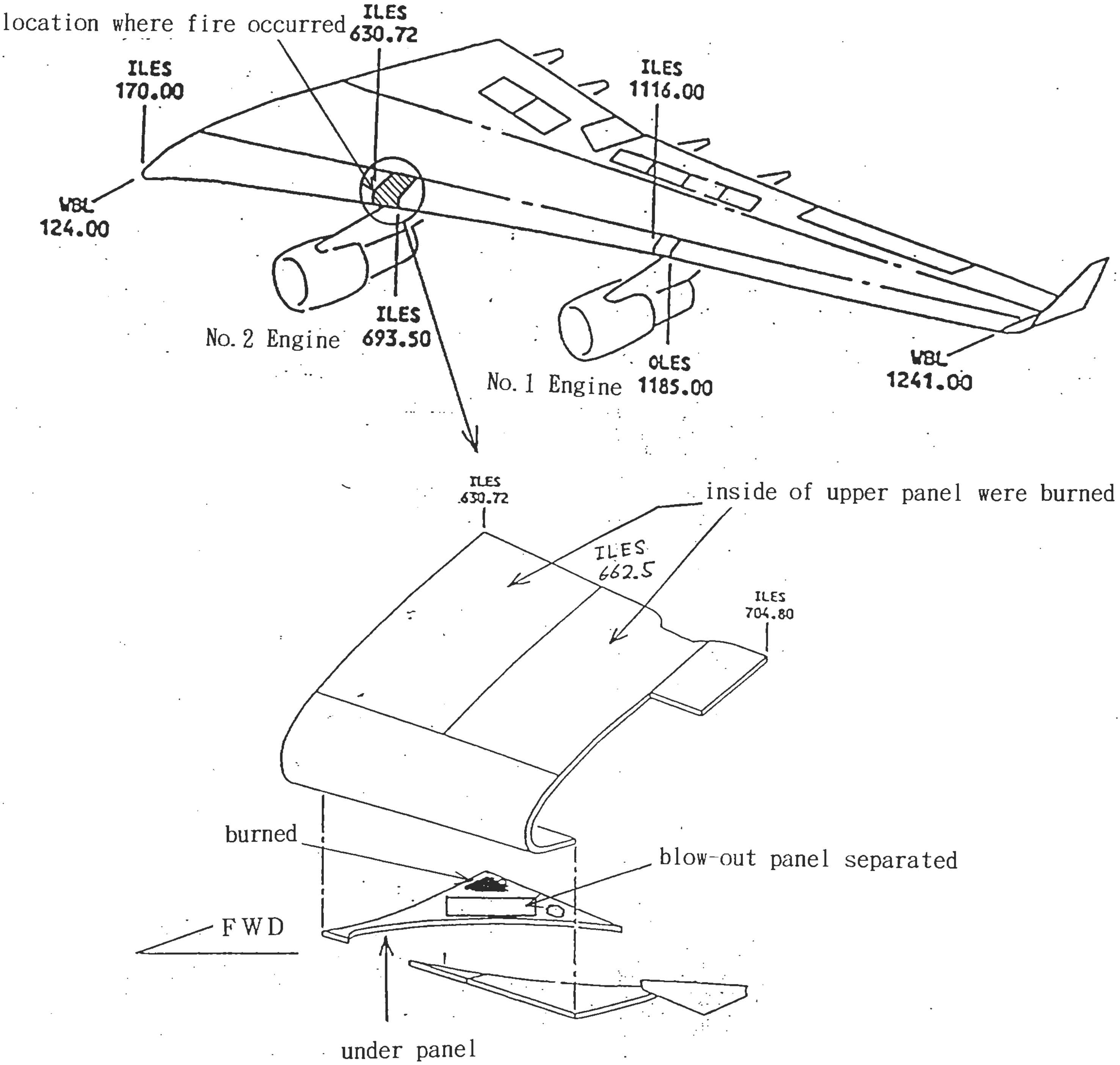


AUPQ30 190000Z SEP 1991 HEIGHT(M). TEMP(C). ISOTACH(KT)

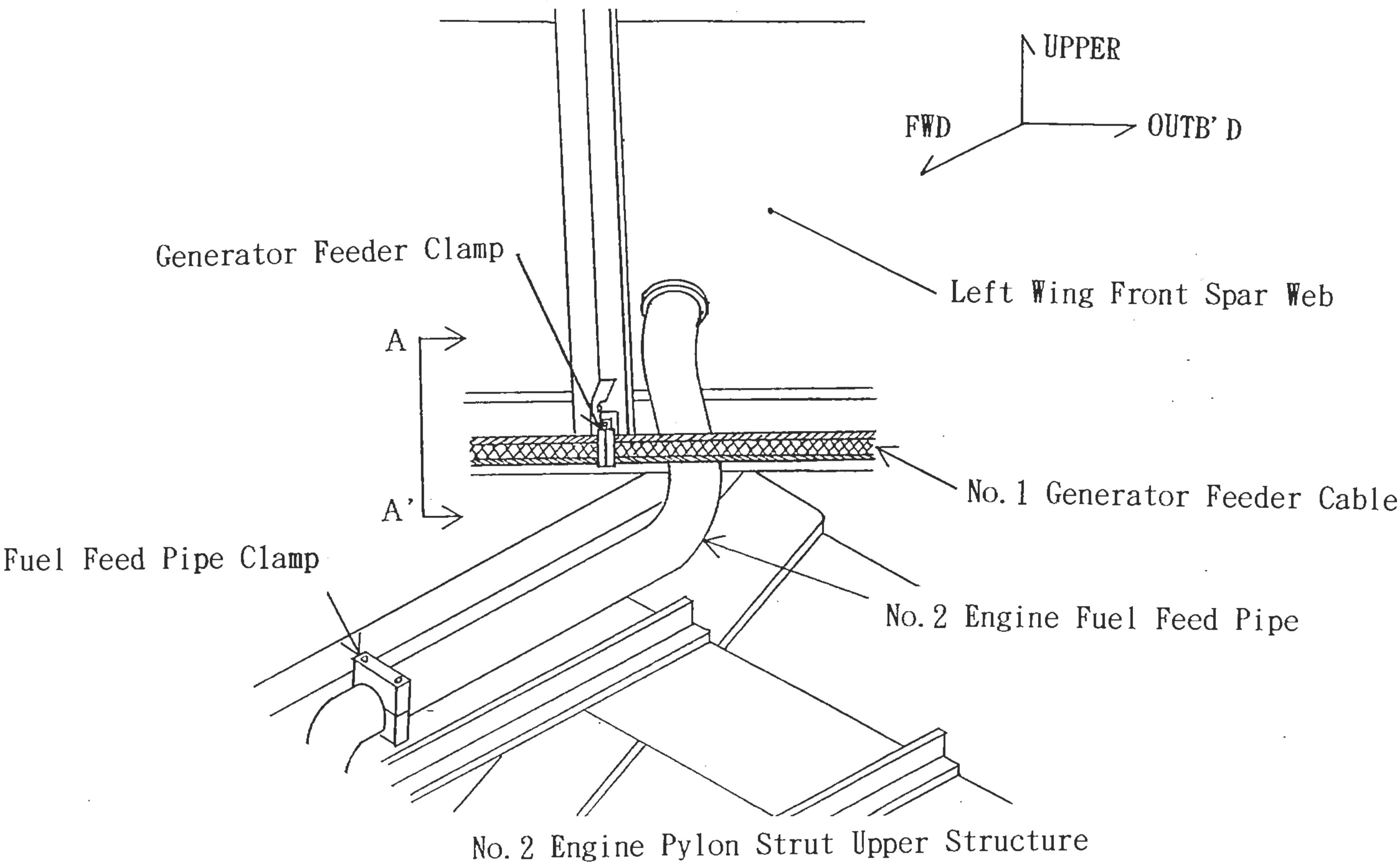


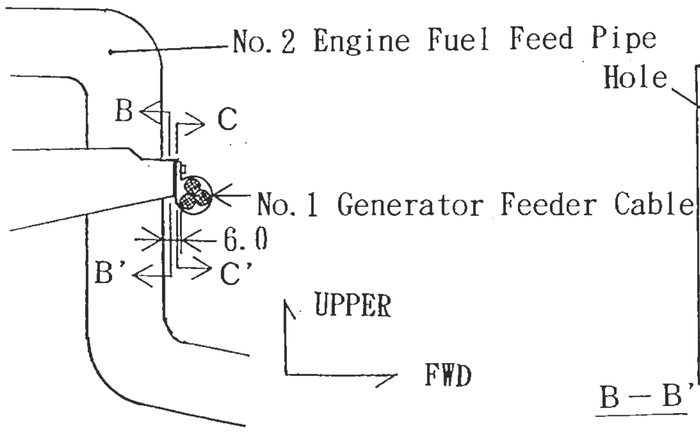
AUPQ30 191200Z SEP 1991 HEIGHT(M). TEMP(C). ISOTACH(KT)

Attached Fig. 5 Location where fire occurred within Left Wing Leading Edge

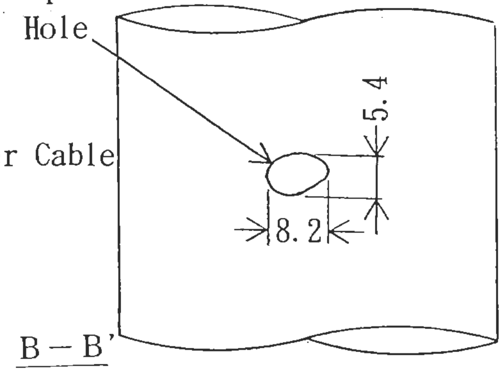


Attached Fig. 6　Damage to No. 1 Generator Feeder Cable and No. 2 Engine Fuel Feed Pipe



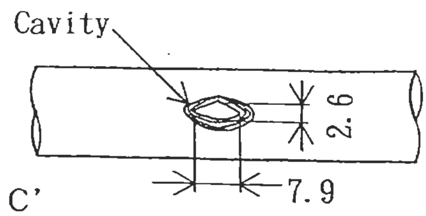


A－A'



B－B'

No. 2 Engine Fuel Feed Pipe

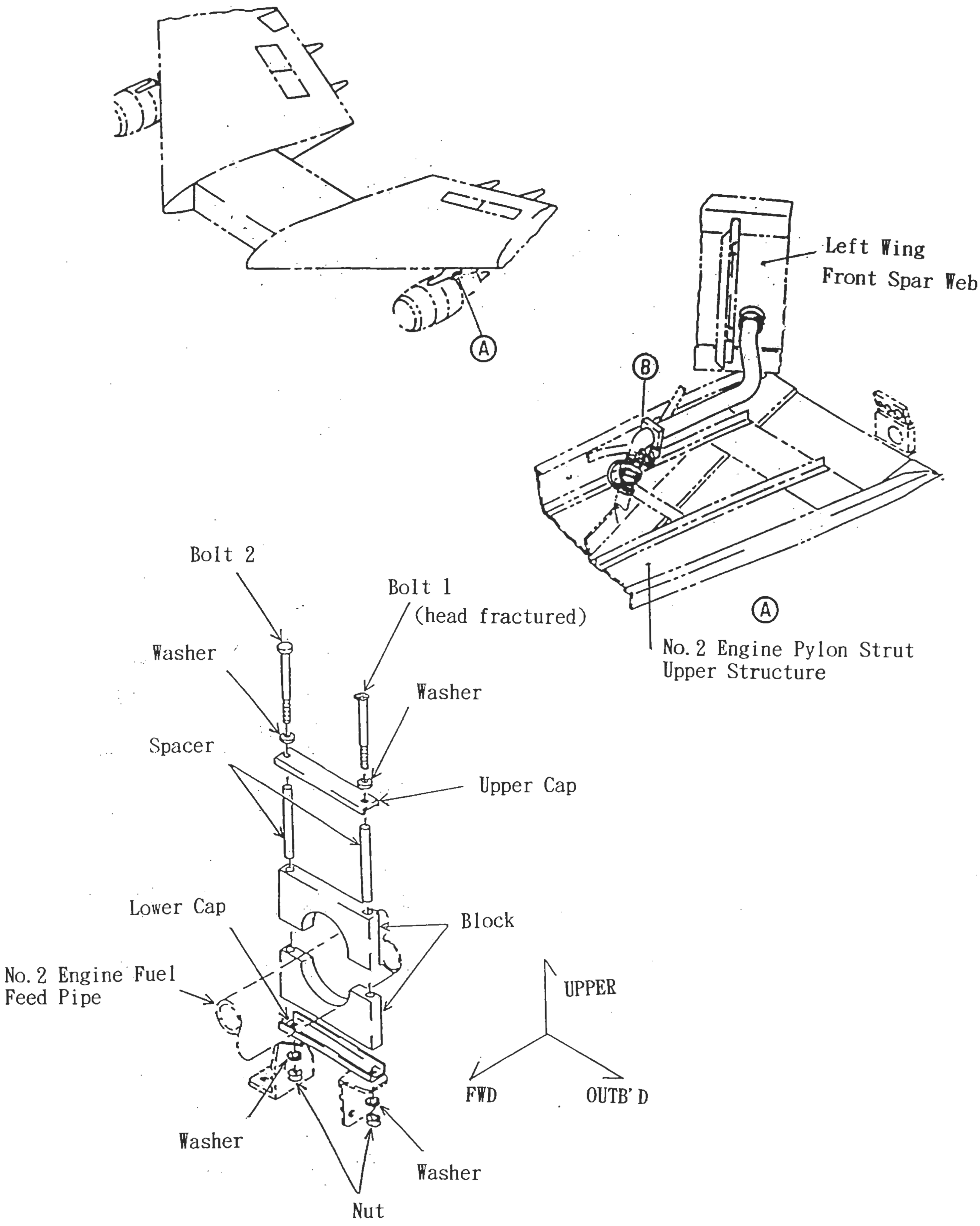


C－C'

No. 1 Generator Feeder Cable

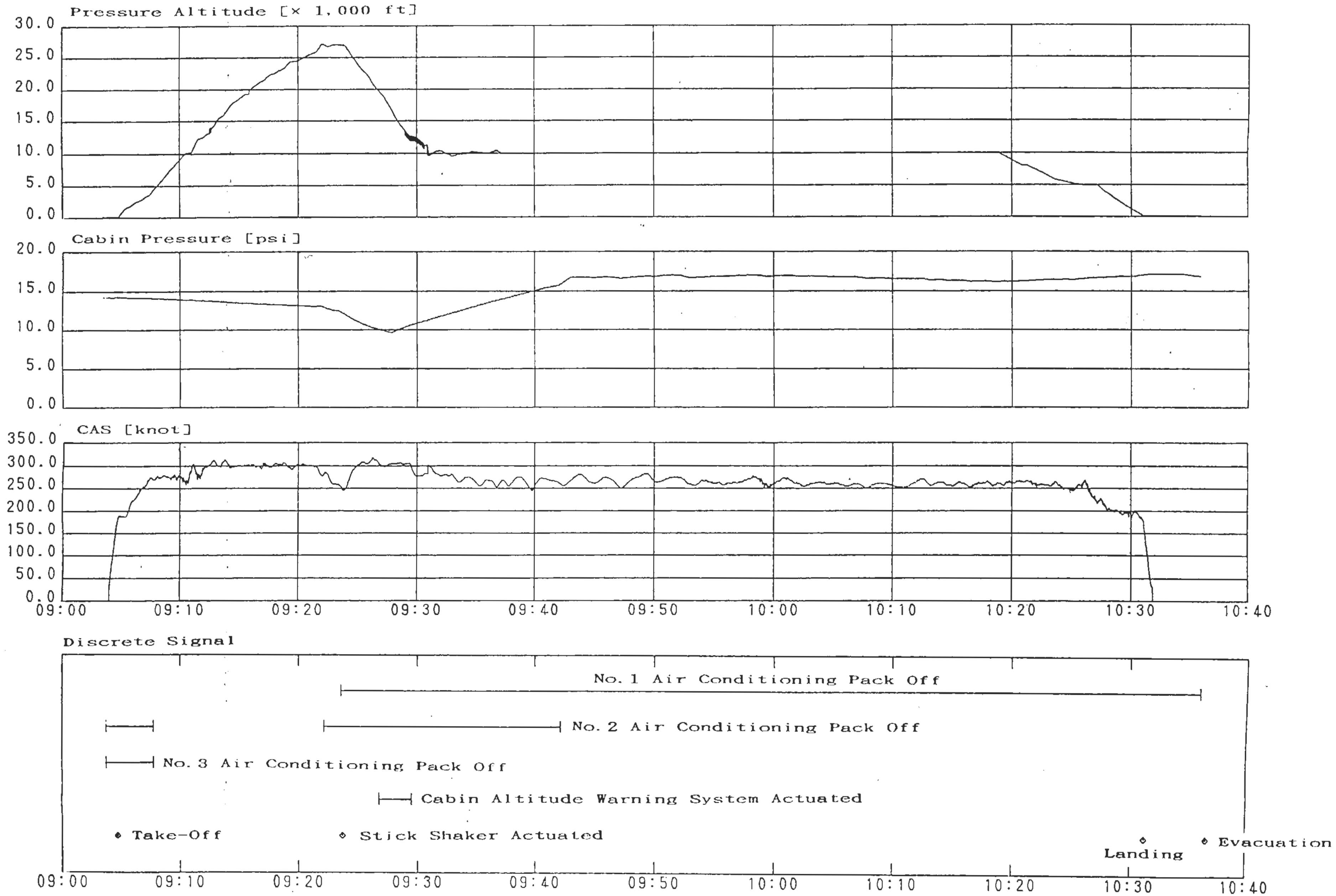
unit: mm

Attached Fig. 7 No. 2 Engine Fuel Feed Pipe Clamp

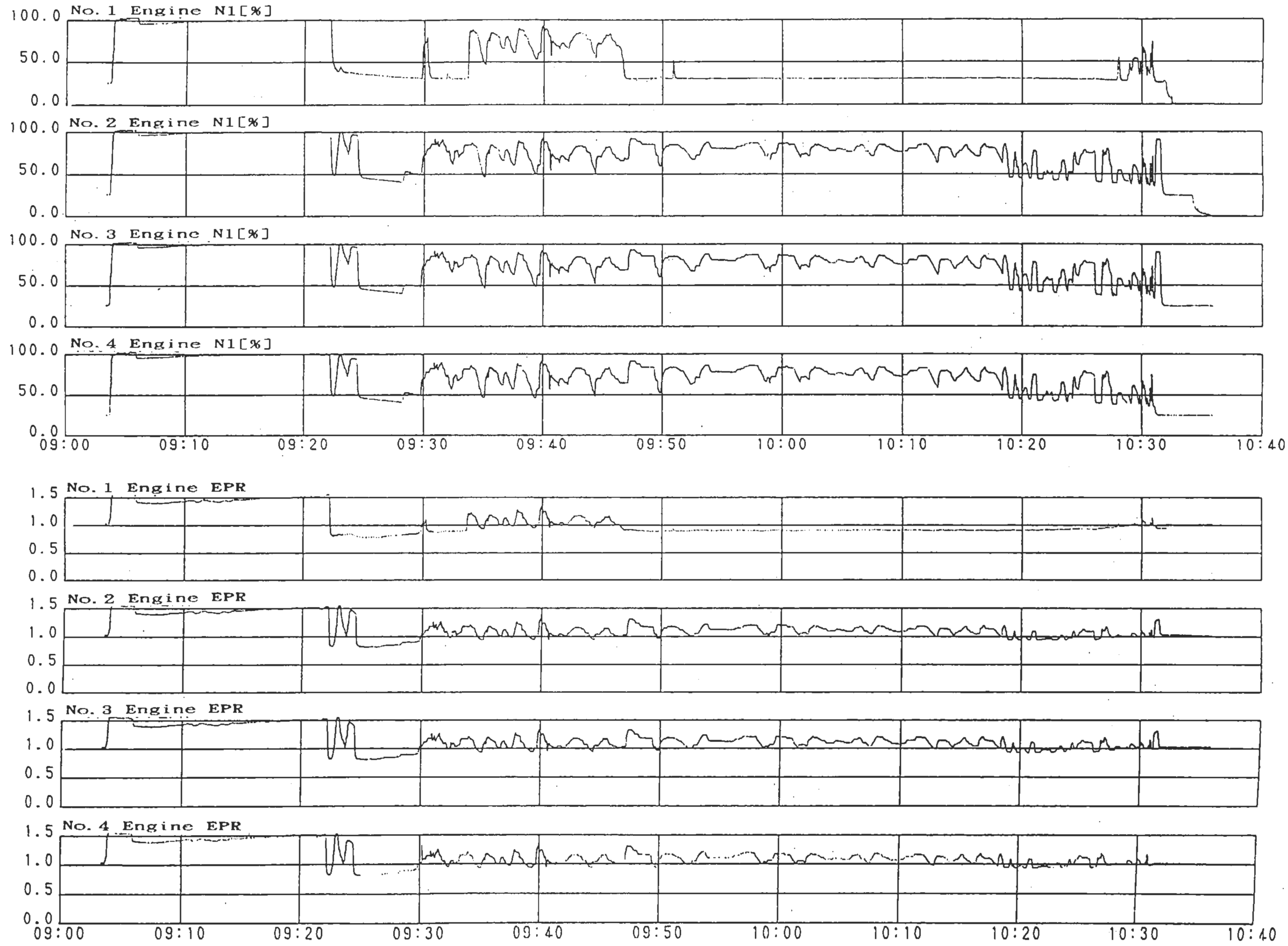


Ⓑ No. 2 Engine Fuel Feed Pipe Clamp

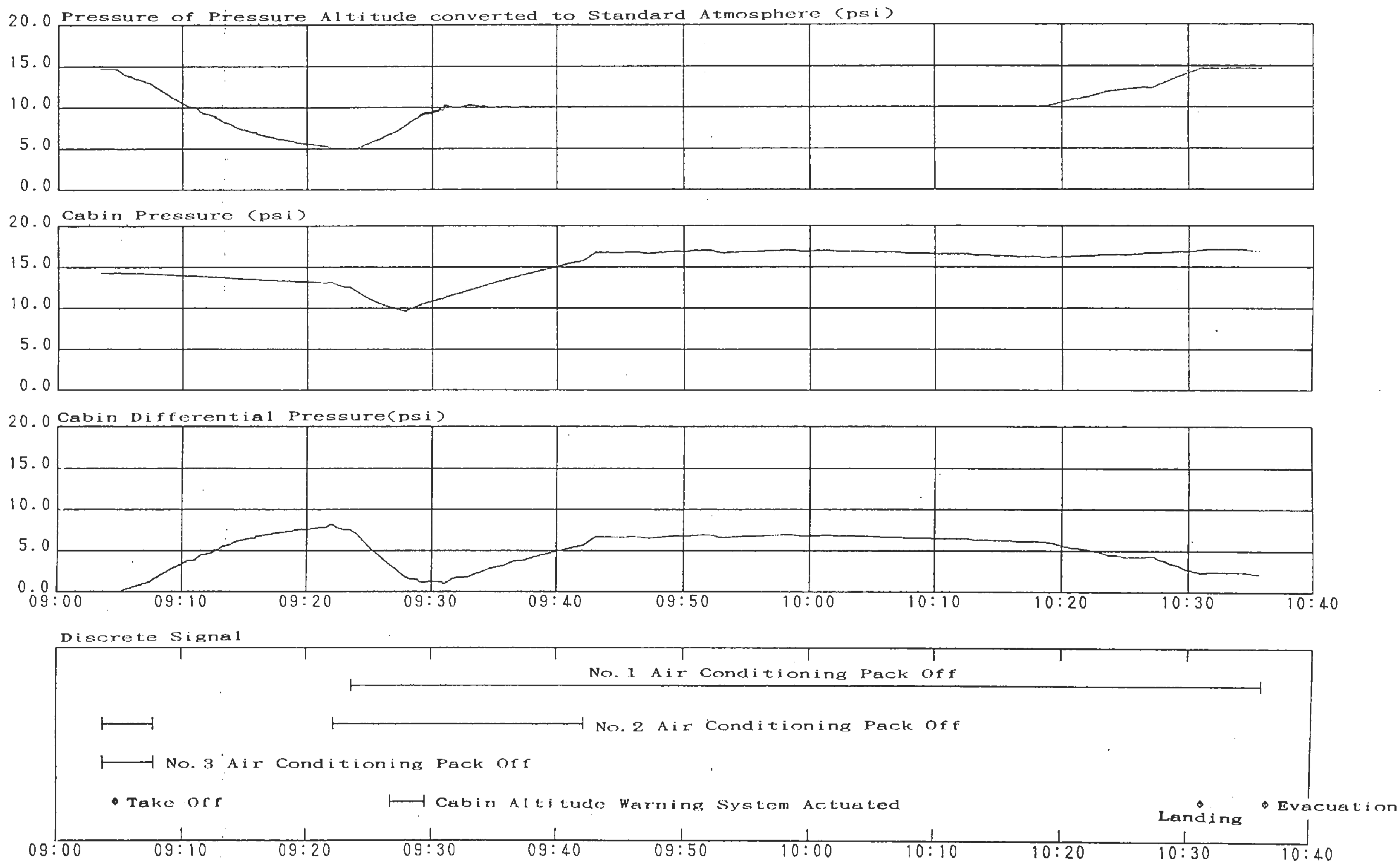
Attached Fig. 8　DFDR Records



Attached Fig. 8　DFDR Records (continued)

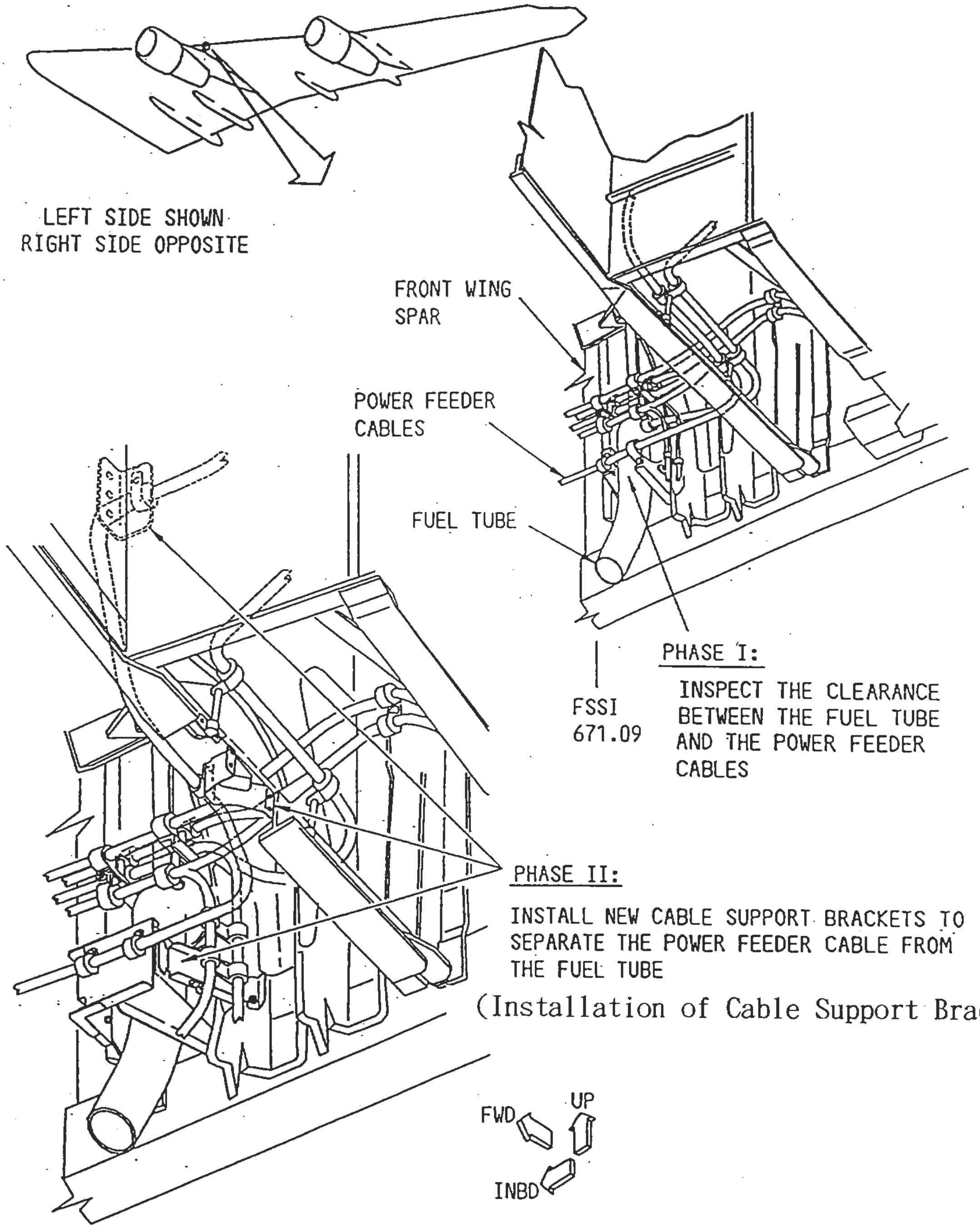


Attached Fig. 9 Status of Cabin Pressurization



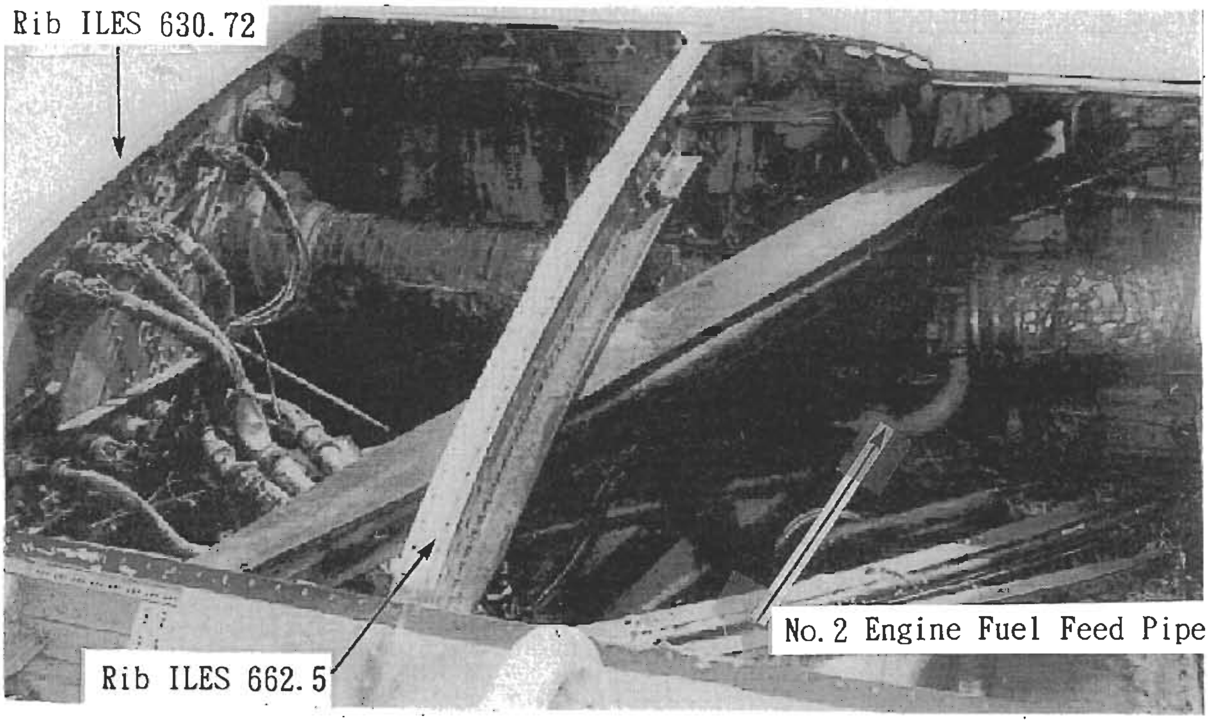
Attached Fig. 10 Modification by Boeing SB of installation of No. 1 Generator Feeder Cable Support Brackets

(BOEING SERVICE BULLETIN 747-24A2168)



(Installation of Cable Support Brackets)

Photе. 1　Location of Left Wing where fire occurred



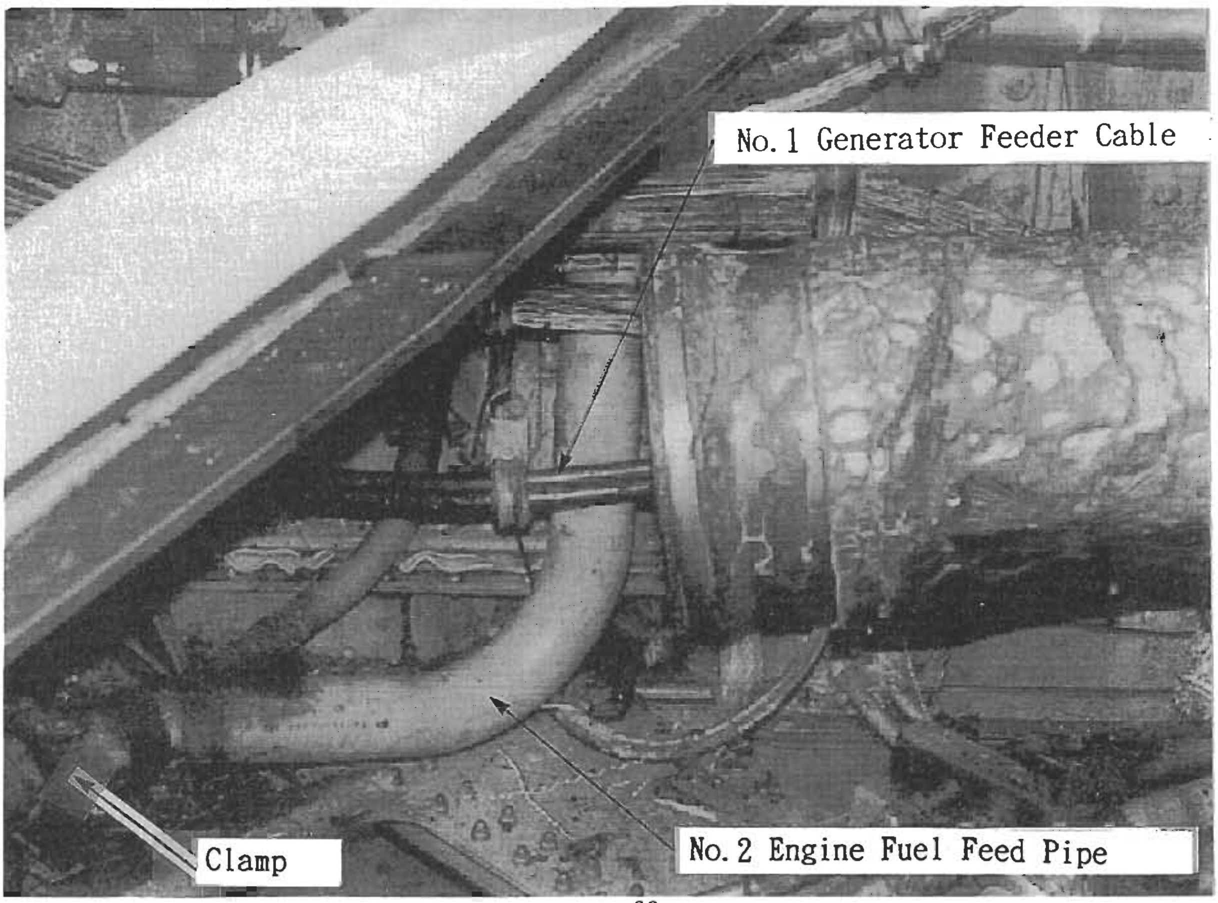
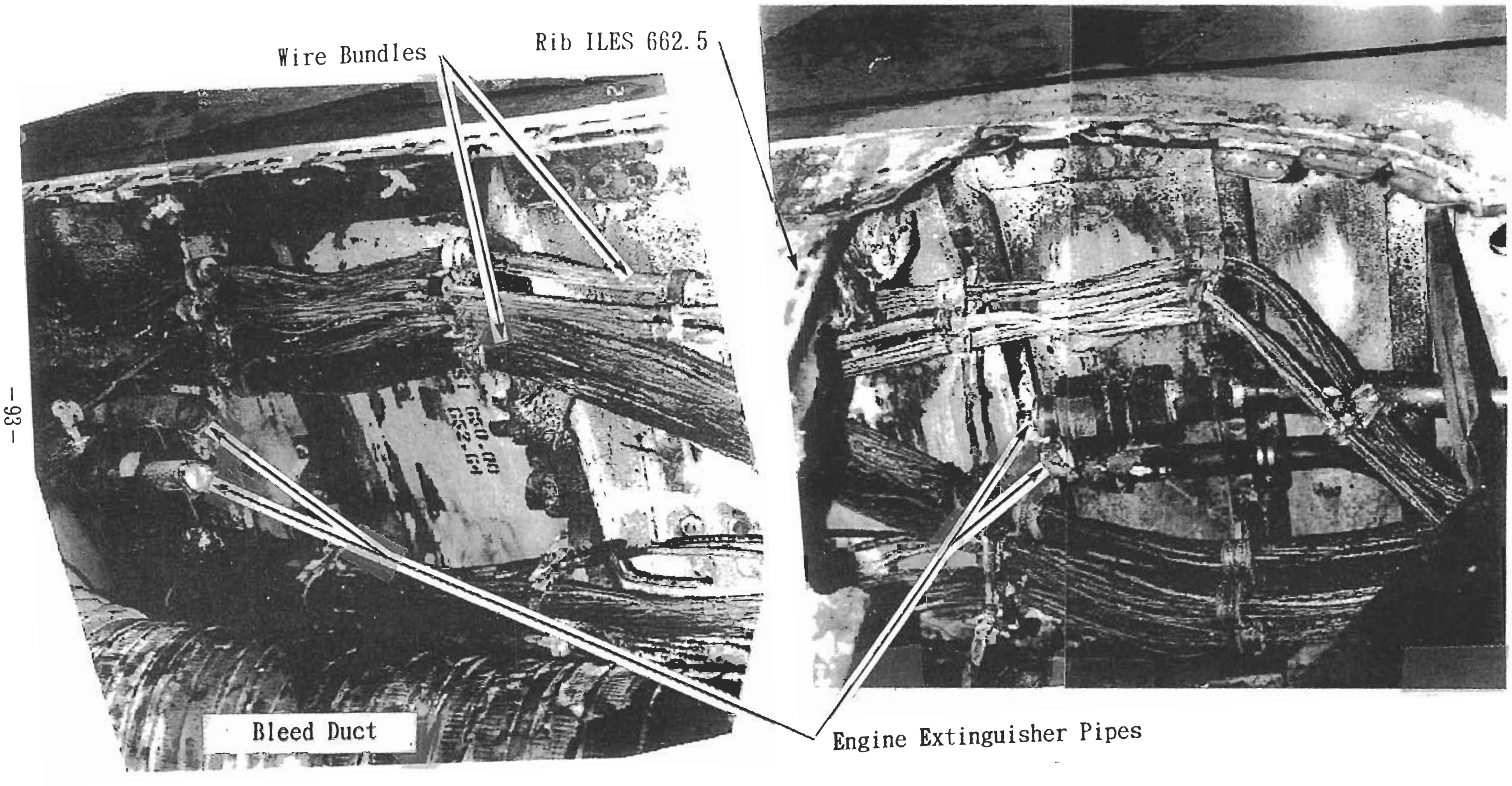
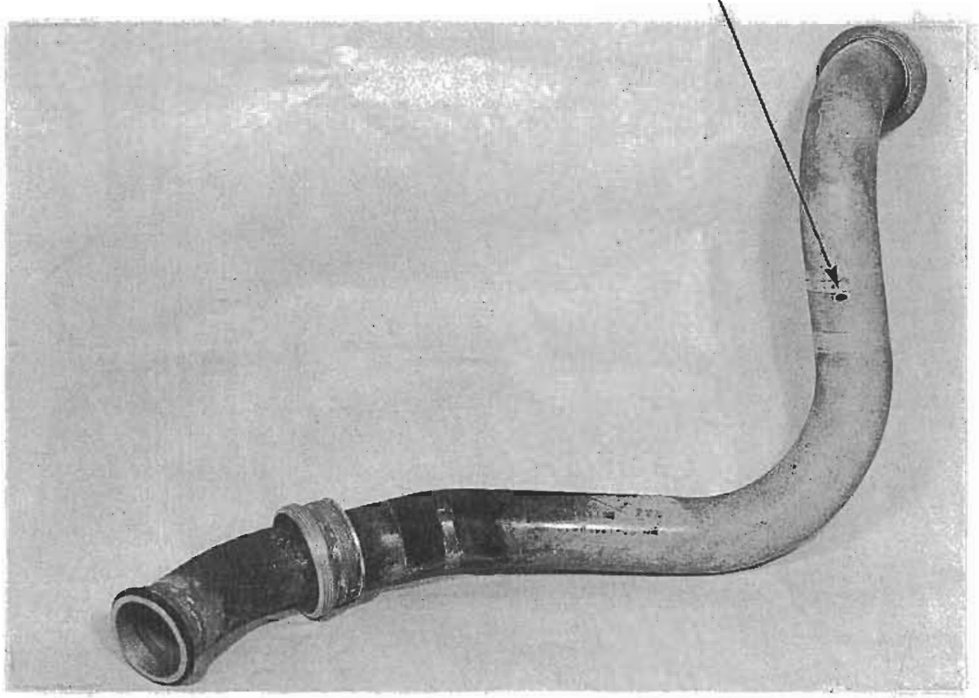


Photo. 2 Wire Bundles and Extinguisher Pipes burned within Left Wing Leading Edge



Phote. 3　No. 2 Engine Fuel Feed Pipe

Damaged Portion of No. 2 Engine Fuel Feed Pipe (Hole)



Phote. 4　Damaged Portion of No.2 Engine Fuel Feed Pipe (EXPANDED)

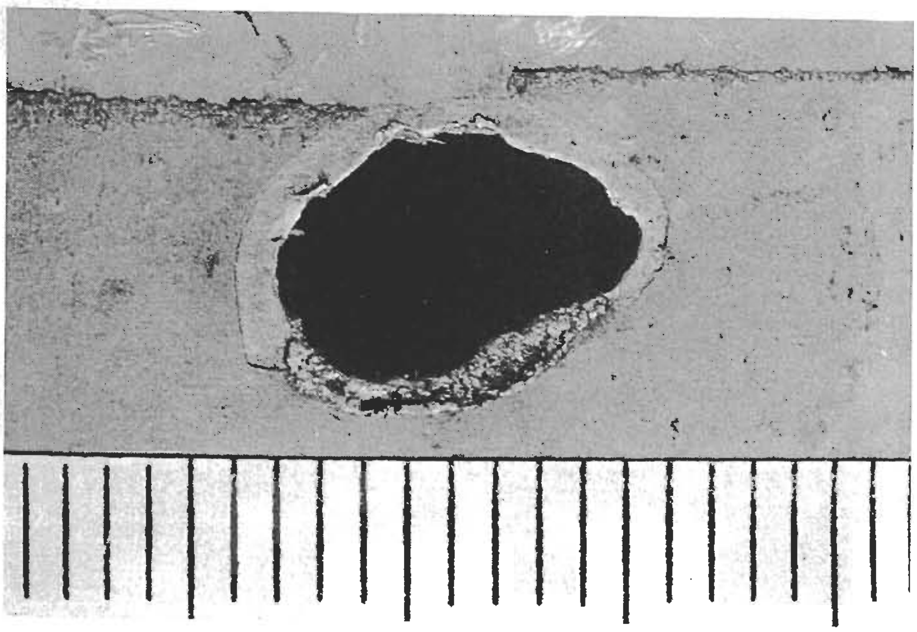
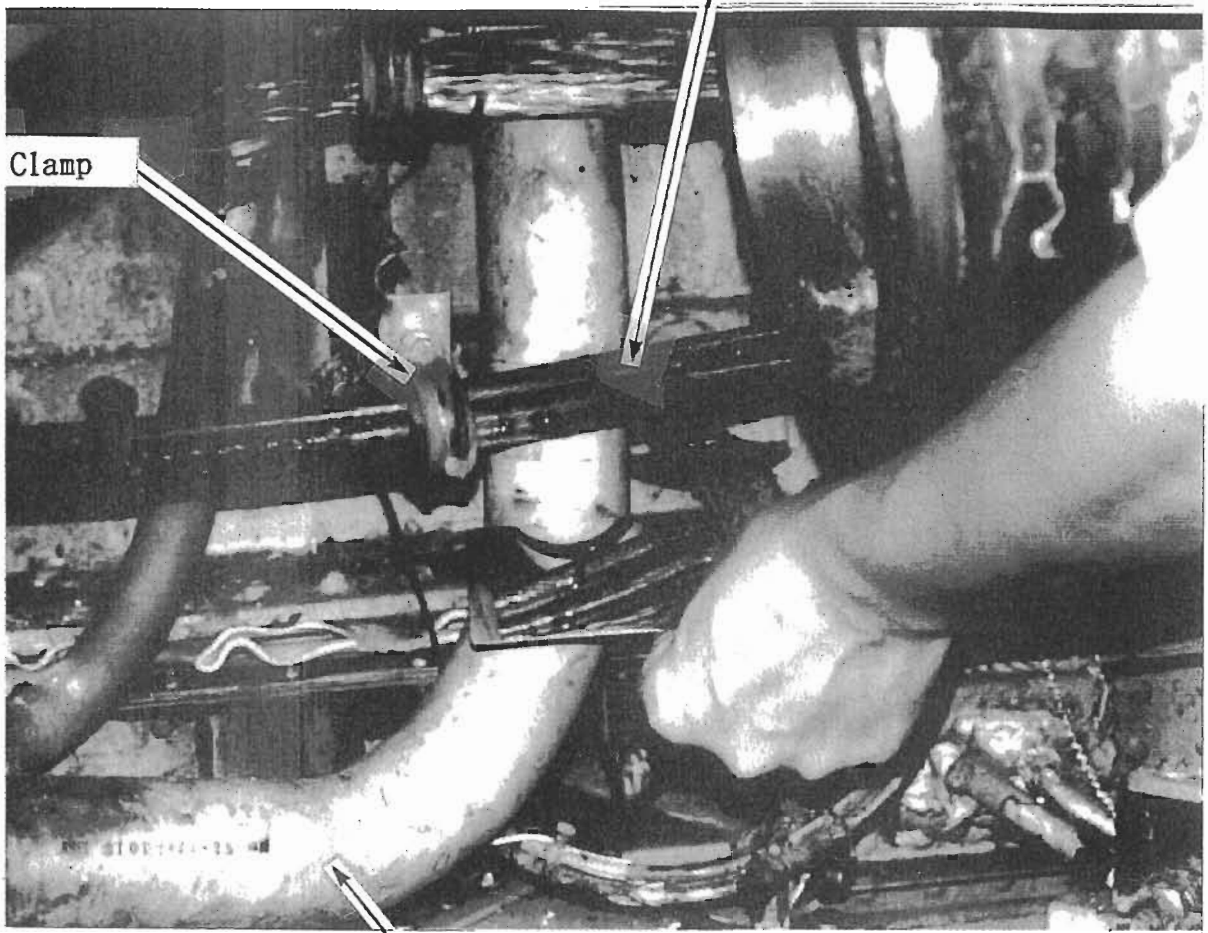
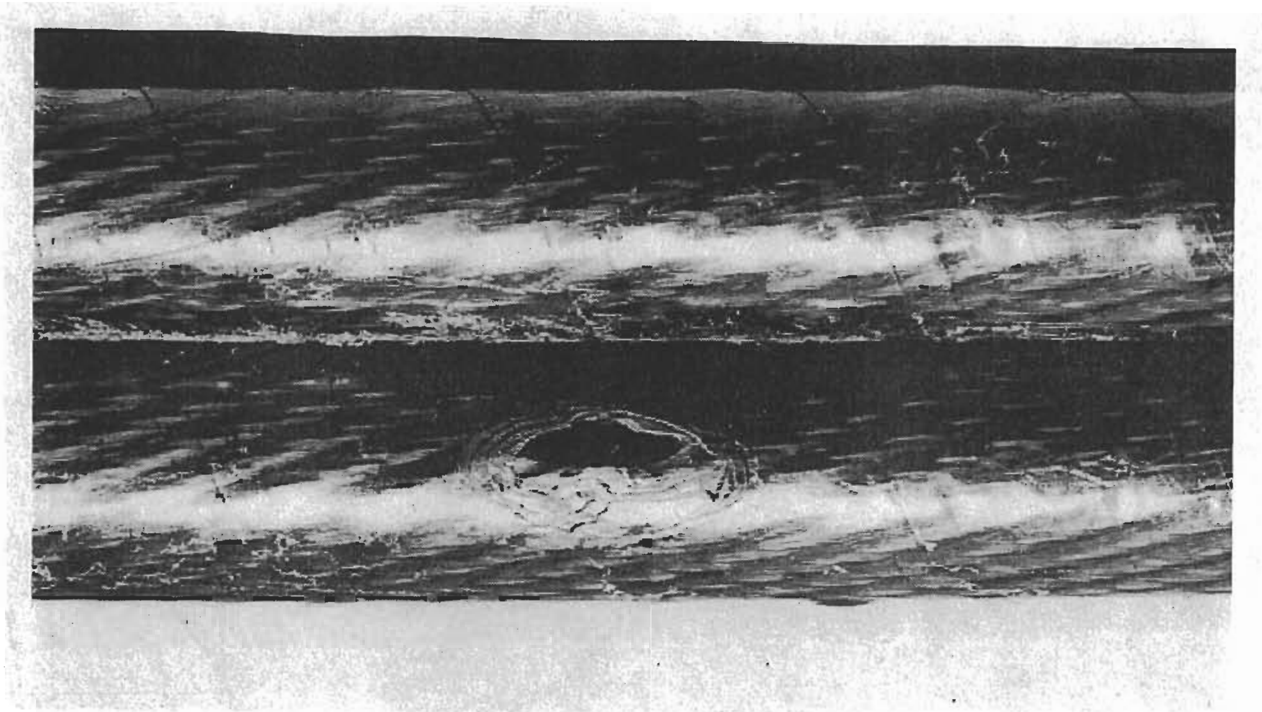


Photo. 5 No. 1 Generator Feeder Cable



Phote. 6 Damaged Portion of No. 1 Generator Feeder Cable (Cavity)



(EXPANDED)